Palmer

Modern Physics Buildings

Rice

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MODERN PHYSICS BUILDINGS

Design and Function

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Design and Function

A project of the American Association of Physics Teachers
and the American Institute of Physics supported by a grant
from the Educational Facilities Laboratories, Inc.

R. Ronald Palmer, Ph. D., Project Director

William Maxwell Rice, A. I. A., Project Architect

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Preface

Early in 1958 a survey carried out by the Committee on Design of Physics Buildings of the American Association of Physics Teachers (AAPT), under the chairmanship of Dr. Yale K. Roots, showed that during the next few years the chairmen of some 200 physics departments expected to be involved in the design or building of new physics buildings for their institutions. The estimated cost of these new physics buildings was close to $250,000,000. Based on the experience of those who had recently completed buildings, it could be anticipated that information concerning the design of these buildings would be sought by staff members of physics departments, college presidents, and architects so that the projected buildings might be most effective for good teaching and significant research.

Although the committee was anxious to assist, it soon became clear that collecting data on the good and bad features of existing buildings and on novel ideas or new products that might improve new buildings was no light task. Full-time help of one or two people certainly would be necessary. To provide funds to employ these people, a request was made by the AAPT and the American Institute of Physics to the Educational Facilities Laboratories, Inc., which had just been established by the Ford Foundation to meet needs of this kind. On September 26, 1958, a grant in the amount of $75,850 was made to the Institute to enable the AAPT and the Institute to undertake jointly an 18-month study of the design of physics buildings. The officers of the two organizations felt especially honored when it turned out that this was the first grant to be made by the new organization.

As a first step in getting the study under way, the AAPT Committee was expanded to bring in a wider variety of talents and was established as an advisory committee to the Institute for this project. The membership of the Advisory Committee is given in the Introduction. Professor R. Ronald Palmer, Head of the Physics Department at Beloit College, was induced to take the directorship of the project and, with the kind cooperation of President Miller Upton, was given a leave of absence from Beloit on a half-time basis for the second semester of the 1958–59 school year and full-time leave for 1959–60. Mr. William Maxwell Rice, an architect with the Ernest O. Lawrence Radiation Laboratory at the University of California and at that time chairman of the American Institute of Architects' Committee on Science and Architecture, was employed as staff architect. The project was carried out in the education department of the Institute under the general supervision of its director, Dr. William C. Kelly. During the initiation and execution of the project, Professors V. E. Eaton, C. J. Overbeck, F. W. Sears, and L. O. Olsen served successively as AAPT presidents.

On behalf of the American Association of Physics Teachers and the American Institute of Physics, it is our great pleasure to express our appreciation to Dr. Harold B. Gores, President, and Mr. Jonathan King, Secretary of the Educational Facilities Laboratories, Inc., for their helpful advice and for the financial support which made this study possible; to the members of the AAPT Advisory Committee who gave so freely of their time and judgment; and, particularly, to Professor Palmer and Mr. Rice for the enthusiastic and painstaking way in which the project was carried out.

LEONARD O. OLSEN, President
American Association of Physics Teachers

ELMER HUTCHISSON, Director
American Institute of Physics

August 8, 1960

Introduction

This book is intended to be of service to college administrators, to architects charged with the design of physics buildings, and to the heads and faculties of physics departments who must foresee their future needs. The authors have worked together as a team since early 1959 on the Project on Design of Physics Buildings. Examples of good design are numerous but are spread over a wide geographical area. Consequently, almost a year was spent in collecting material and another half year in bringing our material and the ideas distilled from months of thinking and discussion into form for publication.

Our plans for the project were developed and carried through with the helpful cooperation of an Advisory Committee set up by the American Association of Physics Teachers, whose members are:

- Yale K. Roots, Physicist, U.S. Naval Propellant Plant, Chairman of the Committee
- Albert V. Baez, Associate Professor of Physics, Harvey Mudd College
- J. W. Buchta, Associate Dean, College of Science, Literature and the Arts, University of Minnesota
- Carl E. Howe, Chairman, Department of Physics, Oberlin College
- Morris Meister, President, Bronx Community College
- Thomas P. Murtagh, Comptroller, L. K. Comstock and Co., Inc., Engineers
- Benjamin L. Smith, Voorhees, Walker, Smith, Smith and Haines, Architects
- William W Watson, Chairman, Department of Physics, Yale University

We made visits to about 50 colleges and universities, where new physics or science buildings had recently been constructed or were under way, and also to a few high schools and a number of industrial laboratories. One of us (WMR) also spent two weeks in Europe, visiting academic and industrial laboratories. In most cases, we obtained copies of the plans and saw the specifications. We had interesting conferences with department heads, apparatus curators, architects, and engineers. They discussed with us the functions for which each building was designed and how the design and the selection of structural materials were related to serving those functions.

We learned a great deal from their reports on the mistakes they would avoid if they were doing the job over again, as well as on the good results achieved. We found electrical services and ventilation to be matters of universal concern. We took hundreds of photographs and many notebooks full of field notes, measurements, and impressions.

A special conference on electric services was attended by the following participants, whose ccoperation is greatly appreciated: Donald S. Brereton, General Electric Company; Frank P. D'Esopo, The Wiremold Company; W. Ditmars, Rogers and Butler, Architects; W. C. Elmore, Swarthmore College; G. G. Harvey, Massachusetts Institute of Technology; Scott C. Jordan, Standard Electric Time Company; Gustave R. Keane, Eggers and Higgins, Architects; Wayne Koppes, Rensselaer Polytechnic Institute; John K. Major, Western Reserve University; V. M. Newton, Hampden Engineering Corporation; Charles Scharfe, Jr., L. K. Comstock and Company, Engineers; Daniel E. Sullivan, Westinghouse Electric Company; Herbert H. Swinburne, Nolen and Swinburne, Architects; Robert B. Watson, University of Texas; Frank Winckowski, Voorhees, Walker, Smith, Smith and Haines, Architects.

A meeting of the Advisory Committee to consider high school physics facilities had the benefit of participation by E. Joseph Piel of the East Orange (N. J.) High School and R. W. Schulz of Purdue University.

We are grateful to the many other people who have given us help in this project, of whom we can mention only a few. Miss Nancy Zlobik served as secretary from the beginning of the project. For a month in the summer of 1959, John Major joined our group to study building services. Mrs. Margaret T. Llano guided the book through the final stages to publication.

Much of Chapter 1 was prepared by Henry A. Barton and of Chapter 12 by William C. Kelly. Valuable contributions to the writing of chapters were made by the following: John Major, Chapter 2; Robert S. Shankland, Chapter 5; Newell S. Gingrich, Chapter 6; William Miller, Chapter 7; and Robert E. Maizell, Chapter 11. In addition, the following persons have read and criticised preliminary drafts of certain chapters: H. A. Fairbank, Karl R. Honaman, E. Joseph Piel, M. B. Sailsbury, Benjamin L. Smith, Wallace Waterfall, and Mark W. Zemansky.

The project was administered by the American Institute of Physics and we have benefited greatly from the active interest of the Director, Elmer Hutchisson, who participated in meetings of the Advisory Committee and advised us on policy and many other matters. Dr. W. C. Kelly, as Director of Education of the Institute, has been close to the project throughout its life; he read the preliminary draft of this report, and contributed helpful suggestions at every stage.

Finally we wish to express our appreciation for the courtesies we received at every institution we visited and our thanks to those who filled out questionnaires, sent us floor plans and photographs, and provided us with critical evaluations of their facilities. We are sure they join us in hoping that this report will help others who have the opportunity—and the problems—of designing a physics building.

R. RONALD PALMER
WILLIAM MAXWELL RICE

August, 1960

1. Space Requirements of Physics

FACTORS DETERMINING THE SPACE REQUIREMENTS

American colleges and universities have realized that their physics departments face a growing task. A recent survey made by a committee of the American Association of Physics Teachers revealed that these institutions have in various stages of consideration a total expenditure of some $250,000,000 on buildings to be used wholly or partly for physics. In the light of current trends in the United States, this sum, large though it is, probably would be inadequate to provide for the needs of the near future even if it were all spent for physics facilities alone.

It is appropriate at the outset to give evidence of the growing "physics load" in institutions of higher education. First, there is a growing public realization that physics has come to be an important part of the general equipment of an educated man, one who will vote, hold office, manage a business or exert any influence. This is because physics has come out of the ivied cloisters and become a great force in the world to be directed for good or ill. As a result, a growing portion of the whole student body of a college or university may be expected to take at least one course in general physics. Second, the demonstrated resourcefulness of trained physicists has convinced the large enterprises of government and industry that such men should be employed in increasing numbers. In response to this demand, there is a growing number of students who are heading for the profession of physics and who will elect a number of advanced physics courses. The National Science Foundation, in a recent report to the House of Representatives Committee on Science and Astronautics, referred to scientific manpower requirements for national defense and then stated, "Increasing international economic competition if cold war tensions are relaxed will put similar, although less spectacular, pressure upon research and development, production, and training with their own science manpower implications. Either of these alternatives will be accompanied by expansion in Government support of scientific research, development, and training programs, which are now in the neighborhood of $8 billion annually.

"It is possible that neither a war ('hot' or 'cold') nor an economic conflict will face the Nation over the next five years—but such a possibility seems quite unrealistic. If such should be our good fortune, one would expect a rapid economic expansion. It would be based on technology, and the development of new products growing out of scientific discovery would be a chief characteristic. Its requirements for a scientifically trained work force probably would be only slightly—if any—less than under the more probable alternatives. Such a development might result in the substitution of more diverse motive forces, but it would not reverse the science and engineering orientation of the economy."

The interpretation of such general considerations in terms of the physics load for which a specific institution should equip itself is difficult. Data are lacking on the current national rate of growth in the percentage of students in entering college classes who will take a beginning physics course. One survey indicates that in 1959–60 there were 239,700 students enrolled in beginning courses. The facts of enrollment should be known at each institution for the past several years. The trend for the most recent years can then be projected, taking into account *both the rising total enrollment* of the institution and *the rising fraction of the total who elect to take physics.* Facilities for beginning physics courses can be adjusted accordingly.

As for advanced courses, some guidance may be derived from national statistics. The U. S. Office of Education of the Department of Health, Education and Welfare has published the total number of bachelor degrees for a number of years and also the number of such degrees awarded to students who majored in physics. The latter do not represent a large percentage of the total but this percentage is now rapidly rising. An analysis recently published indicates that the number of physics majors in 1970 will constitute a fraction of the total more than 50% higher than at present (1960).[1] If this estimated increase be taken in conjunction with the greatly expanded total college enrollments projected by the Office of Education, it appears that the number of physics majors will nearly triple in the next ten years. This may quite possibly be exceeded if facilities and faculties are adequate.

The number of physics graduate students in institutions offering work for advanced degrees has increased from 5,000 in 1954 to 8,500 in 1960 and is still going up. It is, of course, at this level that future professional physics teachers and researchers emerge. The training of graduate students constitutes more of a load on the faculty than on the facilities except for experimental thesis work which may require considerable space. Most graduate students assist in teaching beginning courses or in research projects of faculty members.

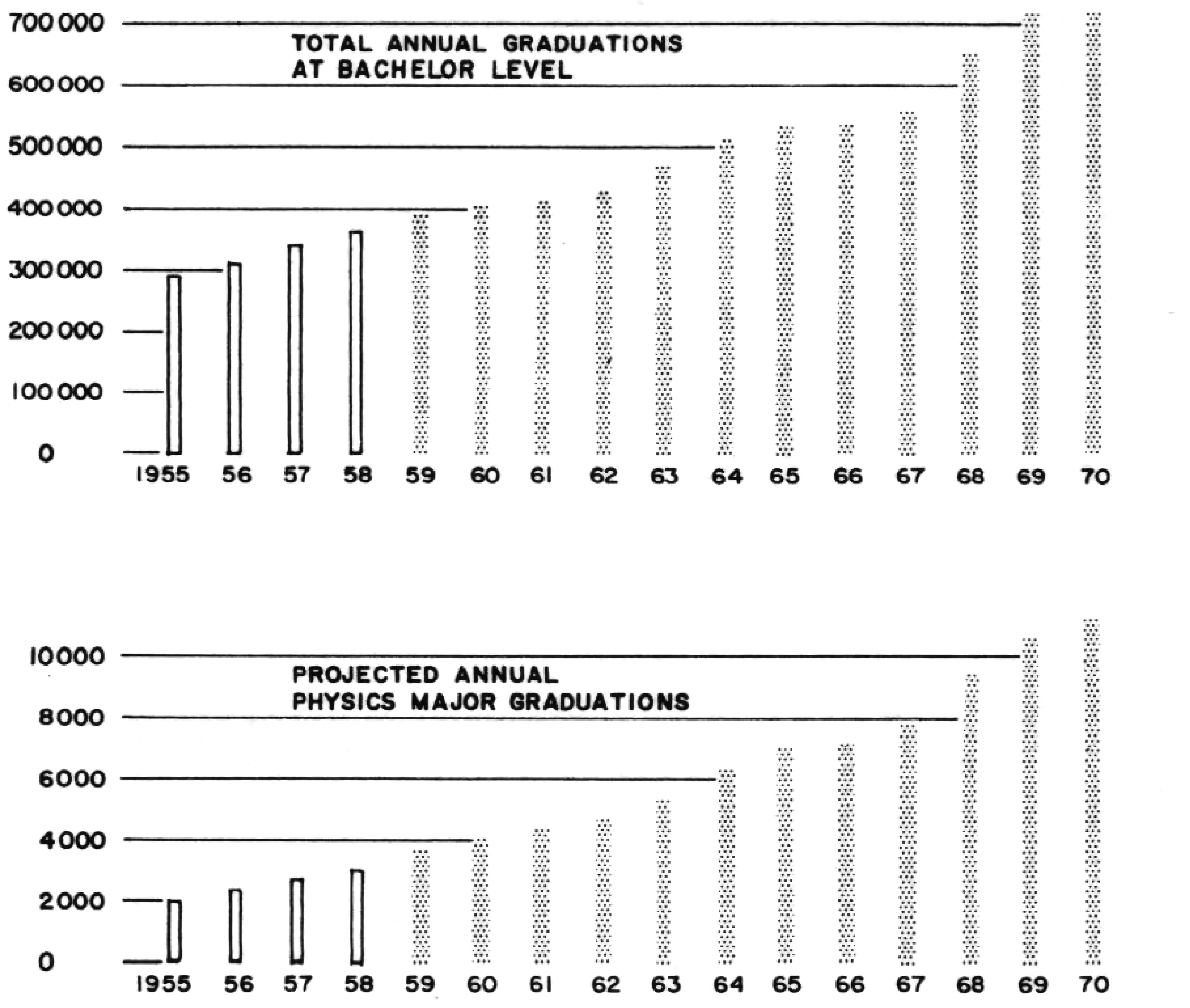


Figure 1. Projected annual B.A. degrees in all fields (top) and in physics (bottom) based on past data.

Research activity at academic institutions can also be expected to increase, probably in rough proportion to the growth in the number of faculty members and graduate students. In the present national situation, it is the limitation of personnel rather than of available funds which determines how much research work is done. Since institutions vary widely in the degree to which they encourage research, it is hard to make general statements. Obviously this is an important factor in determining the space needs of a particular physics department. The future relative emphasis on research and teaching must therefore be carefully and farsightedly appraised.

It would be most helpful to translate these trends and other considerations into concrete terms of so many square feet of building space, but information is not available to do this. Certain lines of reasoning about the number of square feet now available per student or per faculty member have in fact been gone through, however, and the conclusion has been reached that the expenditure of $250 million would probably add less than 50% to the floor space now used for physics. The inadequacy of this may be seen in the light of the certain doubling and probable tripling of the load in the very near future.

At this point it may be wise to caution against planning on an inadequate scale. Space and its maintenance are less costly items on an annual basis than personnel costs. If faculty salaries continue to rise to meet the competition of industry (particularly severe in physics), this will be increasingly true. It is not good economy to provide space so limited that it lowers the efficiency of personnel. This would be the case even if a sufficient number of physics staff people were available. Since a scarcity of such people will almost surely persist for some years, too much will have to be done by too few for space handicaps to be tolerable.

What has been said up to this point relates to the *amount* of space needed in a physics building rather than the *kind* of space. The latter is determined by the nature of the science of physics, by the objectives and methods of physics teaching, and by the research procedures through which physicists can successfully unearth new knowledge of the physical world. These topics are dealt with in the rest of this chapter and throughout the book.

THE SUBJECT MATTER OF PHYSICS

Physics is primarily concerned with the fundamental laws of the physical world, and most physicists emphasize the adjective "fundamental." Classically, the application of physical laws to useful ends has been left to the field of engineering. However, more recently, branches of physics known by the descriptive titles of "Applied Physics" and "Engineering Physics" have arisen. There is no clear line of demarcation between these areas and "pure" physics on the one hand and engineering on the other; only the extremes can be clearly recognized.

Physics makes use of a fine interplay between experiment and theory. Experimentation involves observation, with the emphasis in physics on quantitative measurement. Quantitative measurements lead to mathematical relationships and these in turn to physical laws which are quantitative in character. Theories are developed to "explain" these laws. The more basic a theory, the more widely does it tie together laws pertaining to diverse phenomena. But theory does much more than this. From theory one can predict the existence of other phenomena, and in experimental attempts to verify these predictions new discoveries are frequently made or it is found that theory must be modified. In either case, this interplay between theory and experiment leads to a more complete understanding of nature.

Physics is evidently a growing science. It is both a body of knowledge and a method of inquiry. As a body of knowledge, its subject matter has classically encompassed mechanics, heat, sound, light, and electricity and magnetism. To these have been added, during the past few decades, such fields as nuclear, electronic, atomic, and solid-state physics. Physicists are continually searching for the broad basic principles which tie together seemingly unrelated phenomena in these several areas. And it is the powerful method of inquiry of physics that enables it to accomplish these ends.

Physics is also a science of great resourcefulness continually providing new direct applications to improve the standard of living and strengthen the economy. Moreover, it is fundamental to other sciences and technologies. In recent years new developments in physics have led to the solution of problems in chemistry, biology, geology, and engineering. For the successful development of valuable practical applications, its body of knowledge and its method of inquiry have proved to be extremely powerful. This is largely the reason that the current heavy demand for physicists and for education in physics has arisen.

An important consideration bearing on space requirements in colleges and universities is the fact that the subject of physics deals with *things* and observable *phenomena.*

That is, it is not devoted exclusively to thoughts and the record of thoughts found in libraries. The scholar of literature cannot interrogate a classical author, but the scholar of physics can and should examine nature which remains available. The apparatus and instruments to do so, as well as the space to house them, are important to him. His library, while important, does not need to be so extensive as, for example, that of the English scholar. In a physics lecture, the student must be able not only to hear well but also to see well from the back of the room. The physics student's other space needs are in some ways analogous to those of the art or music student. In each case the student finds it very hard to gain more than a superficial understanding of his subject without the practical use of instruments or media; and special kinds of rooms, whether studios or laboratories, are required for such use. This applies with even greater force for the research physicist, who is in effect a very advanced student—in many instances the world's *most* advanced student—of some special aspect of nature.

THE OBJECTIVES OF PHYSICS TEACHING

World trends are making it ever more clear that an increasing segment of the population must have an appreciation of the fundamental science of physics and of the successful mode of thought responsible for its remarkable development. This segment must include far more than those going into scientific or technical fields, for whom some knowledge of physics is essential. Ideally a good physics teacher can contribute many things to his students including:

1. A curiosity leading to a satisfying understanding of the physical world in which they live;
2. The critical power to gain a clear idea of the limitations and scope of descriptions and interpretations;
3. An awareness that there are underlying, unifying principles of physics which are expressible mathematically, are very general in their application, and constitute powerful tools in the expression and solution of important problems in nature;
4. An appreciation of the historical, painstaking development of underlying ideas of physics and the great strides taken by certain individuals yielding the knowledge now at our command;
5. A recognition that things can be accurately measured and that quantitative knowledge is far more valuable than mere qualitative knowledge;
6. Above all, a capacity and propensity for *objective* judgments. (All of the development of physics is an exemplary triumph of the objective way of tackling problems.)

The qualities enumerated here are valuable to students in any field. Moreover, some awareness of the actual detailed subject matter of physics itself will make the world a more familiar place for students in later life. For those who go into other sciences and technologies, physics is a basic foundation necessary for the comprehension of their own respective fields.

THE METHODS OF TEACHING BEGINNING PHYSICS COURSES

The methods of teaching physics are under constant study. The American Association of Physics Teachers and the National Science Foundation are sponsoring attempts to improve upon the methods now in use. Evolution and change are to be expected and are made more imminent by the development of new techniques employing films, television and other devices. Currently, beginning courses in physics are generally taught by a combination of demonstration lectures to large groups numbering up to 300 (or even 500 in a few instances), discussion classes of 20 to 30, and laboratories in which students work in pairs or individually in classes of 20 to 30. Textbooks and manuals are also used, but these do not have a primary bearing on space requirements.

Demonstration Lectures

As in other disciplines, lectures in physics generally cover the whole subject matter of the course and are usually given by senior members of the faculty who are especially well qualified for such assignments. As often as time and facilities permit, actual phenomena of the physical world are demonstrated during these lectures by the use of appropriate apparatus.[2] Seeing is not only believing. It also aids understanding and arouses interest. Demonstrations may serve several pedagogical functions; they may clarify a physical principle, illustrate an obscure phenomenon, jar a student's complacency, or raise a thought provoking question without supplying an answer. They are an aid to learning, for the more a student's senses are stimulated by a given problem, the more firmly it is embedded in his memory.

For example, there is no better way for the lecturer to show convincingly the way waves move under various circumstances than to set up a small "ripple tank" in which waves are created by a vibrating paddle. The waves are made visible to the class by means of light projected through the glass bottom of the tank or reflected from the surface of the water. Concepts of wave motion underlie much of modern physics. Again, in the field of electricity it is possible for the lecturer to demonstrate by the use of large-dial ammeters and voltmeters how the electric current in a wire depends on voltage and on the length and diameter of the wire. The meter scales must either be large enough for the whole class to read or be optically projected onto a large screen.

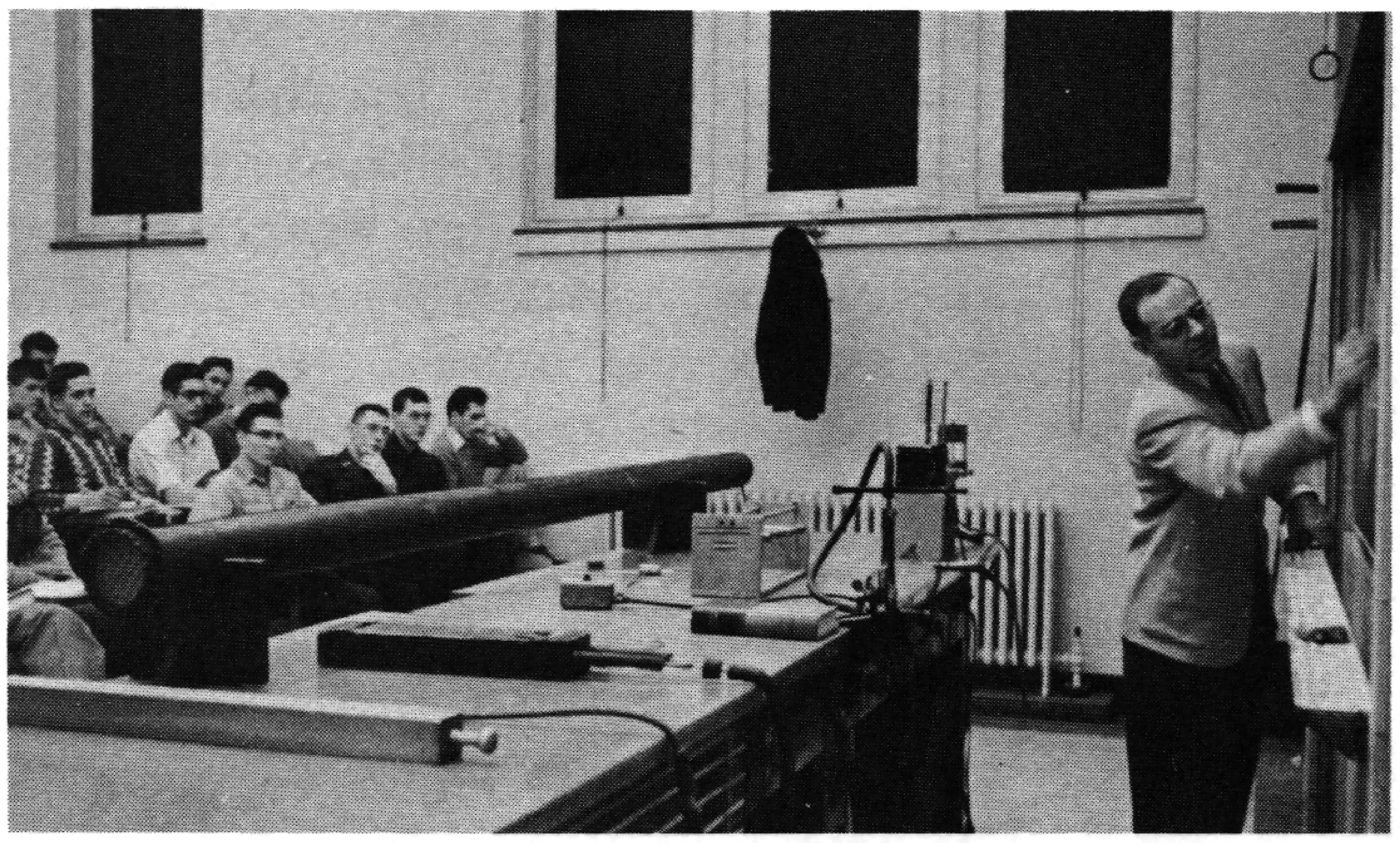


Figure 2. Demonstration lecture.

Since physics lectures involve demonstrations, a room designed for such lectures is usually built with a fairly sharply sloped floor for the space occupied by students, thus affording good visibility. A large level floor area in the front of the room—or a raised stage if the seating space is not sloped—is largely occupied by the demonstration tables on which apparatus may be placed. The tables may be partly fixed and partly mobile, the latter providing for the preparation of demonstrations in an adjacent lecture stock room. This auxiliary room is a sort of property room and staging area. It must be large, immediately adjacent to and communicating with the front of the lecture room through high, wide doors. The stock room and lecture room are a unit.

Details of lecture rooms will constitute a later chapter, but it may be mentioned here that provision must be made for mounting instruments on the wall facing the students without interfering with the usual blackboards, projection screen, and suspensions for large charts. It may also be necessary to provide means for suspending pieces of apparatus from various places in the ceiling. The windows, if there are any, must be provided with light-tight shades which effectively darken the room at a moment's notice. A part of the lecture table must be equipped with sink, water, electrical outlets, gas, et cetera.

The size of lecture rooms is governed by many factors including the size of the student body and the availability of competent lecturers. In order to economize on faculty time, there is a temptation to make the room larger than the ideal in which every student can easily see small objects on the lecture table. If larger rooms are designed, provision should be made for special facilities—optical projection equipment, large demonstration apparatus, and closed circuit television with monitors placed so that no student has a distant view. In fact, even small lecture rooms are frequently equipped with at least one television camera and monitors to show in very close detail small-scale and microscopic happenings. A *main* lecture room seating only 100 is on the low side, suitable only for a small institution. Some run as high as 500 seats; many lie in the range of 150 to 250 seats. It is quite usual to have a second and sometimes even a third smaller lecture room in the range of 50 to 200 seats.

In such matters as seat design and spacing, lighting, heating, and ventilating, the requirements are the same as for rooms for non-physics courses, except that in some demonstrations heat is introduced into the room and the windows often must be kept closed to obtain darkness. There is a growing preference for lecture rooms without windows. In any case, good ventilation is a problem of high priority. Lecture rooms should be on low floors to avoid mass traffic on stairways.

Physics lecture rooms may be used for non-physics lectures if care is taken to protect special equipment permanently or temporarily installed for the physics lectures and if, further, *the room is left free for some time prior to each physics lecture* for the preparation of demonstrations. Even when apparatus for a demonstration can be set up on movable tables in a separate staging room, free time of an hour or two is required to adjust and check its operation after it is moved into place in the lecture room.

The adjacent stock and staging area must be spacious. It is here that the lecturer and his assistant spend much time preparing the apparatus for lecture demonstrations. In fact this sometimes takes more time than the actual lectures. The equipment is stored in cabinets or other suitable space and must be maintained in good order, a process which requires a small tool workbench. At the proper time in each lecture course the appropriate apparatus must be assembled, electrically connected or otherwise serviced, and tested for reliable operation. Movable tables and enough space to maneuver them are necessities. A stock and staging room can serve more than one lecture room provided that it is adjacent to the front of each so that apparatus can be moved to its demonstration place by a short path free of student traffic. Planning this room too small is an easy mistake that should be avoided.

Discussion Classes

The lectures must be supplemented by meetings of faculty members with groups of students small enough in number to permit the usual types of class discussion. Such meetings provide opportunities for the student to ask questions, meet the test of recitation, and take periodic quizzes to measure progress in mastering the subject. The result is a clarification of ideas and some training in precise oral expression.

These classes require a number of "ordinary" sized classrooms such as might be used in teaching any subject. The same rooms are suitable for most advanced undergraduate and graduate courses. Because they are not often used for demonstrations, they can be occupied in successive periods by different groups, affording a use-factor much better than is the case with lecture rooms.

Laboratories for Student Experience

During the laboratory periods, teams of two or more students perform experiments. Usually the students follow procedures outlined in manuals and instruction sheets although there is a trend toward "free laboratory" experiments for which the student is given a minimum of instruction. Experiments usually involve the assembly and operation of apparatus; taking readings in terms of length, time, force, temperature, electric current, et cetera; and reporting the results in written and graphical form. Often, but not always, the experiments illustrate topics covered in the lectures.

Physicists are unanimous in believing that

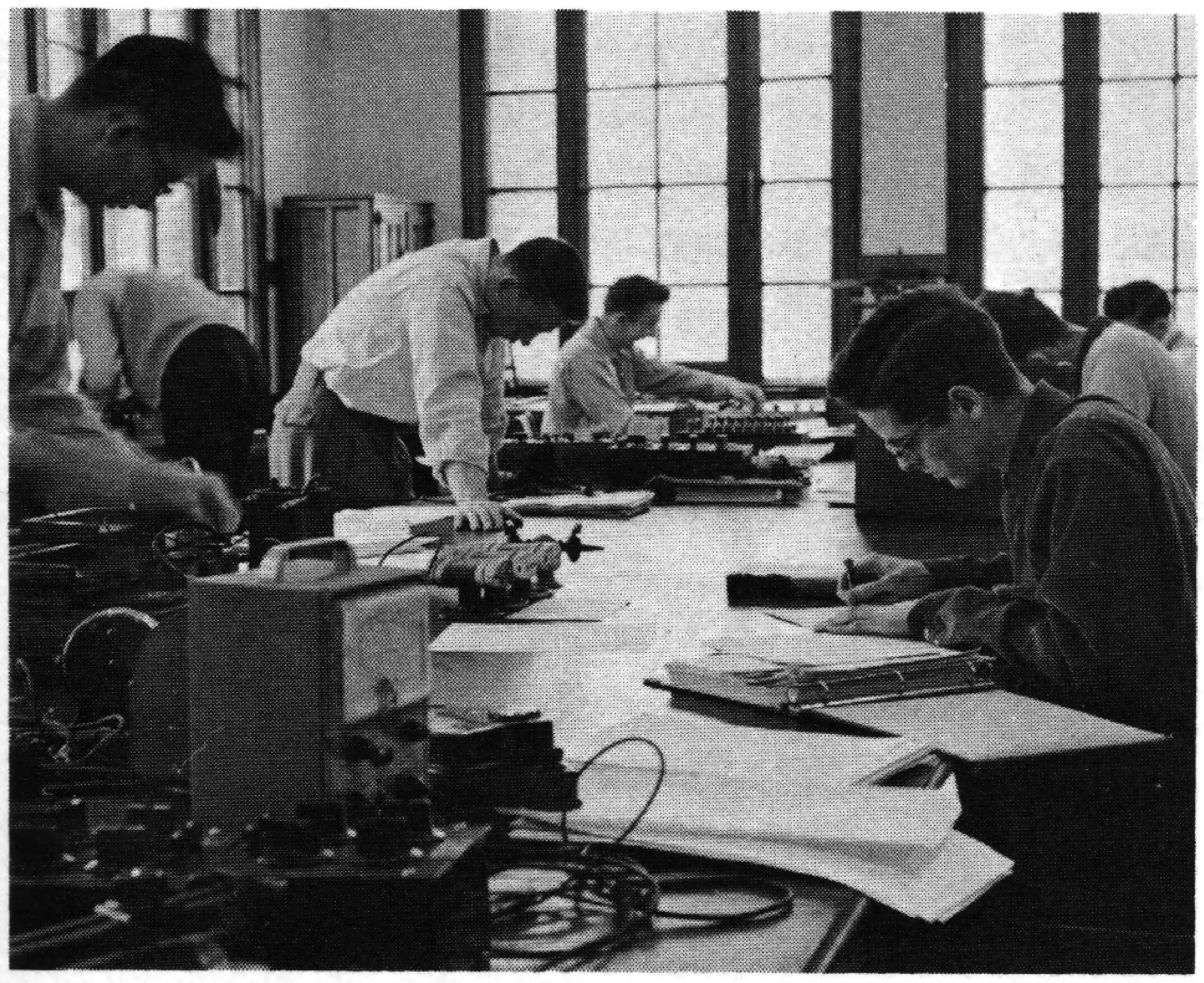


Figure 3. Students at work in an electrical measurements laboratory.

the objectives of physics teaching require for their full attainment more than text books, lectures, discussions, and quizzes. Two or three hours of laboratory work each week are also needed. Direct experience with the phenomena of physics in the laboratory conveys a kind of knowing and feeling not otherwise to be gained. Here is the raw stuff from which physical principles and the physicist's description of reality are derived. The student comes to know physics as a process of inquiry leading to a theory, to understanding. He also acquires the techniques of manipulation and measurement, tests his power to read scientific writings with comprehension, and learns the very useful skill of presenting ideas and information graphically with drawings and charts.

The student in the laboratory is a "physicist for a day" and gains, more intimately than in any other way, understanding of and kinship with the physicist. In a small but real manner, he shares the triumphs and defeats, the sensations and emotions—in short the experience—of physicists. This is a part of knowing physics, particularly as a human activity with social, political, and historical consequences. The reader is referred to a further discussion in an article, "Laboratory Instruction in General College Physics" in the *American Journal of Physics.*[3] It is the report of a conference on the subject sponsored by the American Association of Physics Teachers under a grant from the National Science Foundation.

The laboratory periods associated with beginning physics courses are conducted in rooms without conventional classroom seats; instead they are provided with stout tables, sinks, and outlets for gas, electricity, compressed air, et cetera. The accent is on space that is usable in a variety of ways. In most cases student experiments can be set up on tables, but some require bare floor space for movable stands and equipment such as batteries, motors, and pumps. Some experimental equipment is mounted on the walls. The room should be several times the size of an average classroom to allow a full section of students to work under the supervision of one or more instructors.

Provision must be made for the storage of laboratory equipment not in current use. The equipment is used in turn as it is needed and most of it is in storage at any one time. For example, when the course reaches the topic of heat, the experiments on sound, light, magnetism, and many other topics are put away, and so on for each successive subdivision of physics. Most instructors prefer that storage be in a separate room not accessible to students. One storage room will do for several student laboratories if it is adjacent to them or very near, and is ample in size.

Kinds of Beginning Physics Courses

It is not to be expected or desired that all beginning physics courses will adhere to some standard division of time between lectures, recitations, and laboratory work. Different faculties have different ideas on the subject of physics courses, and this is a healthy state of affairs. The particular practice adopted does however affect the size and number of different types of rooms needed and must be given consideration. Moreover, there are several kinds of beginning physics courses adapted to the needs of various groups of students. An excellent discussion of the subject, with recommendations, is given in the report of a conference sponsored by the American Association of Physics Teachers and financed by the General Electric Company on "Improving the Quality and Effectiveness of Introductory Physics Courses." [4]

Briefly, there are three main types of beginning courses, directed to three different groups: a) physics majors, students of the other physical sciences, and engineering students; b) students of the biological sciences including pre-medical students; c) non-science majors. The conference cited recommended that these courses be accorded not less than ten, eight, and six semester hours respectively. An additional second-year course in general physics should be provided for physical sciences majors and engineers; this is also recommended for mathematics majors and for prospective secondary school physics teachers.

Sometimes courses are offered in "general science" or "physical sciences" or a combination of physics and chemistry, but many persons feel that such courses require unusual competence of the teacher if they are to give even non-science majors enough familiarity with the basic science of physics to cope with the world today. It must be pointed out that, just as methods of teaching physics are undergoing development, ideas as to what is appropriate to different groups of students also are undergoing rapid evolution.

Space Requirements for Beginning Courses

When the distribution of time between lectures, classrooms, and laboratories is known for each type of beginning course, and when estimates for future years as to the number of students taking each type have been made, it is possible to calculate the space requirements. As an example of such a calculation (without implying any recommendation), consider a hypothetical course of 200 students having two lectures a week as a whole group, with one hour of recitation and one 3-hour laboratory for each student, both of the latter conducted in sections of 20. Allowing time to prepare demonstrations, this course will tie up a lecture room seating at least 200 for four to six hours a week, and will require ten hours of classroom time and 30 hours of laboratory time. If it is only practicable to schedule laboratory periods in the afternoon, as is often the case, such a course will require two laboratory rooms five days a week.

ADVANCED COURSES

In all institutions that offer physics major curricula (about 600 throughout the nation), as well as in certain others, a number of advanced physics courses are given. Such courses, some of them taken by students of chemistry, geology, engineering, et cetera, along with physics majors, are given by faculty members especially competent in their respective subjects. Some of the advanced courses are organized in terms of the traditional subject matter divisions of physics, such as optics, acoustics, mechanics, electricity and magnetism, heat, and thermodynamics; others, such as atomic and nuclear physics, the solid state, and theoretical physics, cut across traditional lines.

Advanced courses differ from beginning courses in that they involve much fewer students but these are usually highly mo-

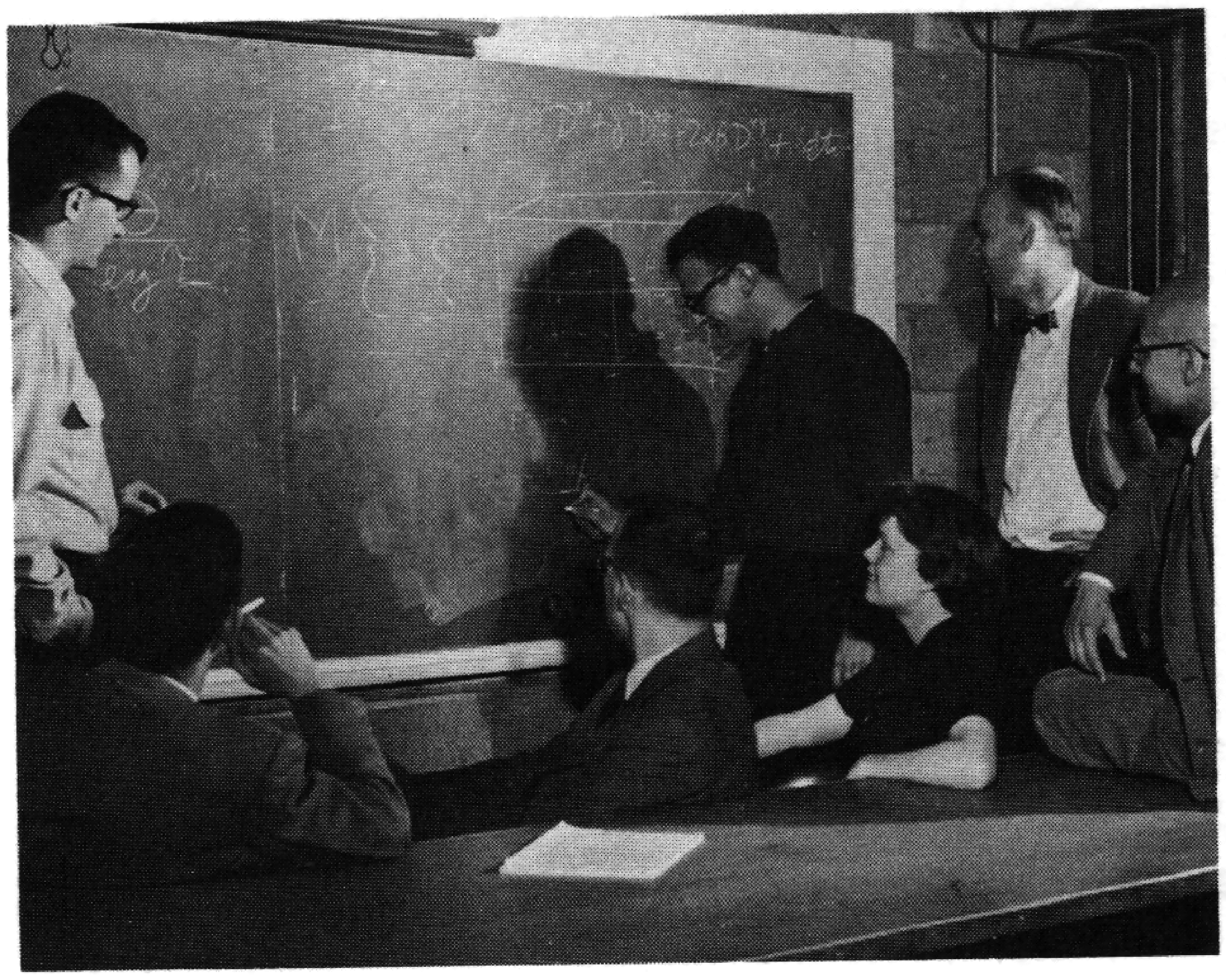


Figure 4. A graduate seminar.

tivated. An easy and productive exchange is generally possible between them and the professor. Many such courses are not accompanied by demonstrations of phenomena so that ordinary classrooms are suitable.

In the past, advanced physics classes, in almost all cases, have been small enough for rooms accommodating 20 to 30 seats. This is no longer so in some large institutions. As the number of physics majors continues to increase, each physics department will have to decide whether to offer the larger advanced courses in small parallel sections or resort to the formal lecture technique with large groups. This decision obviously has a bearing on the number and sizes of classrooms needed in the physics building.

Student laboratory work is not ordinarily made an integral part of the advanced courses. Physics majors do, however, usually take at least one and often two years of a comprehensive advanced laboratory course that requires the exclusive use of well equipped laboratory rooms. As compared with elementary laboratory work, the emphasis here is on more precise measurement with higher quality instruments and on experiments which are much more complex, time-consuming (occasionally days rather than hours), and apt to relate to more recently opened up fields of physics—the world of the atom and its component parts. The student is brought much nearer the front line of research. One might say that his "field" training, as contrasted with his "barracks" training, begins at this point.

Both small and large rooms can be employed for work at this level, and they may include rooms with special facilities and physical characteristics. Provision for the safe storage of valuable equipment is required. Some of the more complex pieces of equipment are left permanently set up. The use factor of such rooms is not high and the number of students involved is a small fraction of those using elementary laboratories. However, these students planning careers in science and engineering represent an extremely valuable resource for the nation and are an important part of the clientele of physics departments.

Graduate courses in physics are essentially theoretical in character and, of course, are designed primarily for the student seeking an advanced degree in physics. In addition to course work, graduate students in many physics departments are encouraged to acquire early research training as assistants in research projects. Later, a thesis requiring an independent investigation, which may be either theoretical or experimental, is universally required of a Ph.D. candidate and often of an M.S. candidate. In many institutions, however, a master's degree is granted on the basis of course work and examination alone. Ordinary classrooms or small lecture rooms do very well for graduate courses. No special facilities other than ample blackboard space and a place to hang charts are needed. Space needs for the research work of graduate students will be discussed in the next section.

RESEARCH ACTIVITIES AND SPACE REQUIREMENTS

Institutions of higher learning have accepted the assignment of discovering and formulating new knowledge, as well as that of imparting to students the store of knowledge already gained. Not all but most college and university faculty members are involved in both of these assignments. They do research, and this helps keep them and the quality of their teaching alive and vigorous. They teach, and this exercises their power of expression, sharpens the clarity of their understanding, and in other ways improves their competence for research. This interplay has been the subject of much thought and has come to be recognized as highly valuable, if not quite essential. One result is that colleges where the opportunity for research is limited by lack of faculty time, funds, or building space, generally have a hard time keeping good teachers. The current high competitive demand for trained physicists in well paid positions in industry and govern-

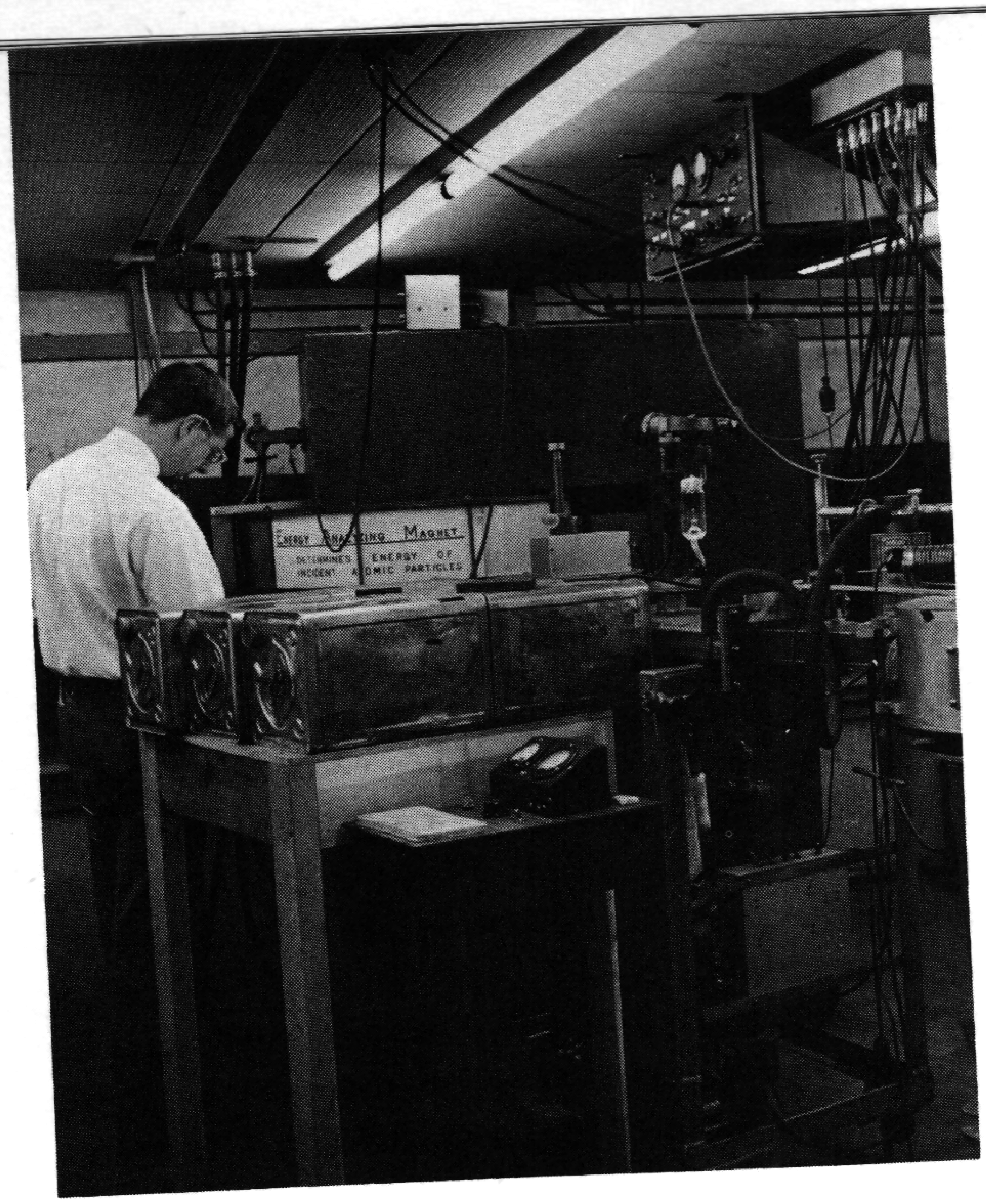


Figure 5. Research apparatus.

ment has brought this difficulty to the point of dire emergency in a number of smaller colleges. Thus even in small institutions, good research space must be provided.

The nation depends on the larger institutions to carry on most of the basic research that is done. Without their contribution, fundamental discoveries, the raw material for the applications so important to industry and national security, would be meager indeed. The quality of academic research is high. American institutions have shared the glory of many Nobel prizes awarded to their professors.

Some research physicists confine their attention to theoretical studies and sometimes need only a blackboard, well stocked book shelves and a desk in a quiet room suitable for concentration. Frequently, however, they require the use of more or less elaborate computers, which in turn require space.

For physicists whose researches are partly or largely experimental, the space requirements are great and extraordinarily varied. One almost despairs of planning research space for the future, but of course it has to be done. One can be sure of some things. Research requires abundant electrical power at a variety of frequencies, gas for fuel, compressed air, water, and frequently air-conditioning. The most adaptable space is the best research space. It may be necessary in a developing research program to take out partitions or even floors and to supply additional electrical and mechanical services.

Frequently annexes or wings must be built specially for large scale equipment such as cyclotrons, research reactors, large spectrographs, and anechoic chambers.

Research rooms will house complicated apparatus setups which are assemblies of purchased instruments like oscilloscopes and pulse-height analyzers, large items like electromagnets constructed on order in industrial plants, special equipment made in the physics department's own shop, and quantities of wiring, tubing, and other supplies. These assemblies take months to construct and may pre-empt the space they occupy for years of productive research. Enough research space must be provided not only for the faculty, but also for the research thesis work of graduate students, however many of these there may be.

Once constructed, research apparatus is used to make measurements of many phenomena including radiation, nuclear particles, conduction of electricity in solids and gases, behavior of materials at high and low temperatures and pressures, and so on ad infinitum. Out of such research in the future will come new knowledge and new useful applications comparable to X-rays, radio, transistors, "tracer elements," and nuclear fission.

SUPPORTING FACILITIES

Library

In contrast to his colleagues in literary fields, the physicist does not generally find in the library the actual materials for his research. He does, however, look there for guidance in planning his research, benefiting from the experience of others; and for factual information and data necessary in connection with his research. Because physics is a rapidly advancing field of knowledge, much of the information needed is unlikely to be found yet in books, but rather in recent issues of scientific periodicals. Of these there are a great many, published mostly by scientific societies and appearing from all civilized nations. The American Institute of Physics alone publishes the following periodicals for its member societies and itself:

The Physical Review
Reviews of Modern Physics
Bulletin of the American Physical Society
Physical Review Letters
Journal of the Optical Society of America
The Journal of the Acoustical Society of America
Noise Control
American Journal of Physics
The Astronomical Journal
The Review of Scientific Instruments
The Journal of Chemical Physics
Journal of Applied Physics
The Physics of Fluids
Journal of Mathematical Physics
Physics Today

In addition, it publishes English translations of voluminous Soviet periodicals of physics. The physicist uses his library primarily for (a) quickly scanning the new literature for new research reports in his field; (b) reading carefully books and articles presenting pertinent results and background information, and (c) briefly looking up isolated facts, techniques, and numerical data, as needed for his work at the moment.

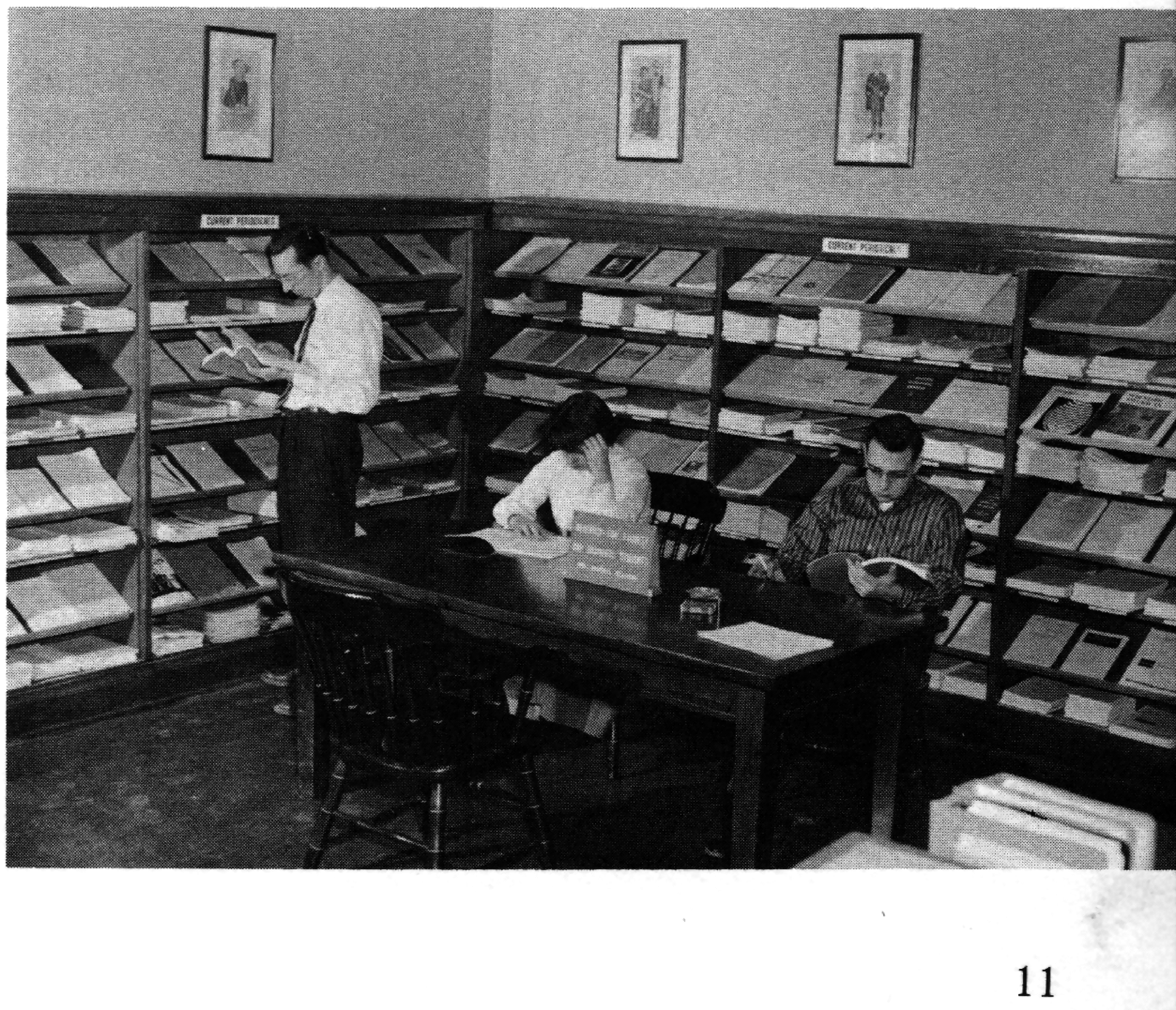
Thus, quick accessibility is important, and periodicals are relatively more emphasized than books. This means, first, that most, if not all, of the physics library collection should be located in the physics building rather than in a central library some distance away. Second, ample space must be provided for the display and use of unbound, very recent issues of periodicals; and these, together with the bound volumes of previous years, should be quickly accessible. A special librarian is needed and must be provided working space.

Librarians should be consulted about future developments in library techniques for which provision perhaps should be made. Such developments may include greater use of microreproductions for storage, and photocopying devices, as well as improved methods of indexing scientific literature, to mention but a few.

Physics libraries are probably not used as much as they should be by students of beginning courses, but they are used a great deal by physics majors, graduate students, and faculty members. If convenient accessibility is not impaired, the physics library can be combined with that of mathematics or chemistry. One or more adjacent private study or conference rooms equipped with blackboards are very useful.

The results of a recent questionnaire conducted by Dr. D. A. Wells of the University of Cincinnati show how strongly physicists feel on the subject of library facilities. The questionnaire dealt with the desirability of combining the separate departmental libraries in a consolidated science library which

Figure 6. Physics library.



would be located in a separate building. Answers from 104 of the 120 departments circulated yielded the following results:

> 84 persons strongly in favor of departmental libraries
> 17 persons lukewarm or "on the fence"
> 3 persons definitely in favor of a consolidated library

One of the 84 qualified his opposition to consolidation of science libraries "under one roof" by adding "unless it happened to be my roof!" (A more detailed analysis of the questionnaire results will appear in the *American Journal of Physics.*) It should be stressed that the questionnaire pertained to a consolidated *science* library. Had it involved consolidation in an all-university library, it is safe to say that the opposition would have been still greater.

Administration and Other Offices

Physics professors do not have fancy ideas about their personal surroundings. On the other hand, it is no economy to give them insufficient space in which to conduct the business of the department. Such business is considerable. It includes the registration of many undergraduate students for various courses for which their readiness must be verified, assignment of students to sections, preparation and marking of examinations, the recording of grades, and discussion with students about individual problems and the like. Other functions are the examination of applications for admission as graduate students; handling of "personnel" problems and department policy matters; care of the teaching and research equipment; planning, designing, purchasing, or overseeing the construction of research apparatus; participation in university committees and activities; correspondence with colleagues elsewhere, and participation in the activities of learned societies; not to mention the actual teaching and research which could not go on without these supporting activities.

As in other departments, the senior faculty members need individual offices adequate for interviews, study, and "desk-work." Junior faculty members can sometimes share office rooms or use research rooms as part-time offices. In some departments, each large course has an office with cubicles for instructors.

Storerooms

In addition to the usual janitorial storerooms and the like, a physics building requires special storage facilities of various kinds. Some of these needs have been mentioned in connection with lecture rooms and student laboratories. There must also be storerooms for research equipment and supplies. The equipment is apt to be valuable and fragile, as it includes electrical, optical, and other sensitive instruments. It must be safely stored on shelves and in cabinets; it is often dispensed more or less formally by a responsible attendant; for example, it may be charged out as library books are. Smaller institutions require less formality than larger ones. There will also be a lot of motors, batteries, pumps, magnets, tanks for oxygen and other gases, apparatus mountings, et cetera, many of which are heavy enough to require floor space of their own.

Expendable supplies and small parts are used in great quantity in research. They include a stock resembling that of a do-it-yourself radio or electrical shop with some aspects of a hardware store, plus such things as rubber tubing, laboratory glassware, foil, waxes, lacquers, mercury, chemicals of many kinds, and so on, including enough items to make a large catalogue. Being necessarily a Jack-of-all-trades, the research man needs the tools and supplies of all trades.

Shops

Shop facilities for the construction and maintenance of apparatus and instruments are an utter necessity to a physics department—even a small one. Machine tools of

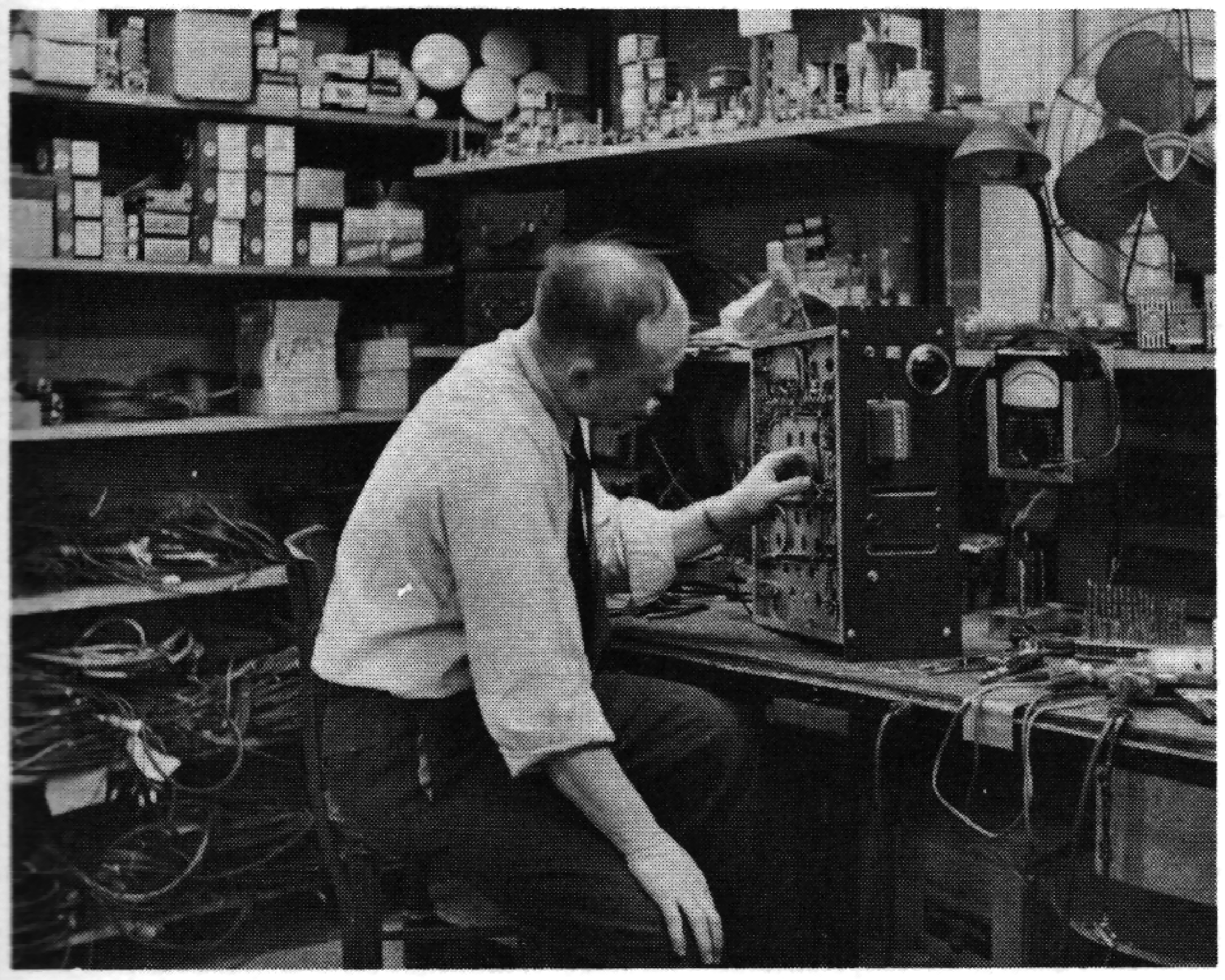


Figure 7. Electronics shop.

the usual types for metalworking and woodworking must be available, together with some delicate, precise tools such as a jeweler's lathe. Most shops are divided into student shops, where simple tools and work benches are available for unsupervised use, and machine shops in charge of one or more skilled mechanicians. The head shop man is one of the most important people in the department. The greater part of the shop time in large departments is devoted to serving the equipment and construction needs of those doing research; thus, the size of shop needed depends mainly on how active a research program is maintained. There is a minimum shop size, however, even in small departments where teaching is preponderant over research. In every department, the shop contributes to the design and production of lecture demonstration and student laboratory equipment, often supplying valuable devices which cannot be readily obtained from manufacturers. Such work requires all of the ordinary machine tools.

Shops are generally in the basement where strong flooring and foundations can most readily be provided for machine tools. Care in mounting is necessary to avoid transmitting undue vibration to the building structure, which might prevent delicate experiments and measurements from being carried out in the laboratories. Adjacent to shops, space is needed for the storage of wood and metal stock, cutting tools, machine attachments, lubricants, and other shop supplies.

No reference has been made to the frequent availability of a central shop of the university or college. Some of the physics department's work can be done in such a shop. This might include extra heavy work, mechanical operations seldom needed, or some kinds of routine maintenance or production of standard equipment items. The physics shop is primarily a development shop. The mechanician and the researcher work together to achieve some purpose often completely novel, and this requires frequent conferences at all stages. For this kind of work the shop should be located in the physics building.

Many physics buildings have glass blowers' shops equipped with burners, annealing ovens, glass lathe, and storage bins for glass stock. Other special shops, located near research areas, are frequently needed, depending on the types of research activity carried on. An example is a shop for electronic circuitry.

Other Auxiliary Rooms

Special rooms of various kinds may be needed, including dark, sound-proof, and constant-temperature rooms. One or more rooms may be needed for equipment supplying direct and alternating current at various voltages, compressed air, sometimes rough vacuum, liquified gases for low temperature research and lecture demonstrations, et cetera. An attic or "morgue" is a good thing in a physics building. Retired components of earlier research apparatus often find re-use with considerable saving of time and money.

Unloading Space and Elevators

It should be possible for a large truck to deliver a heavy piece of equipment to a basement door with a sheltered exterior plat-

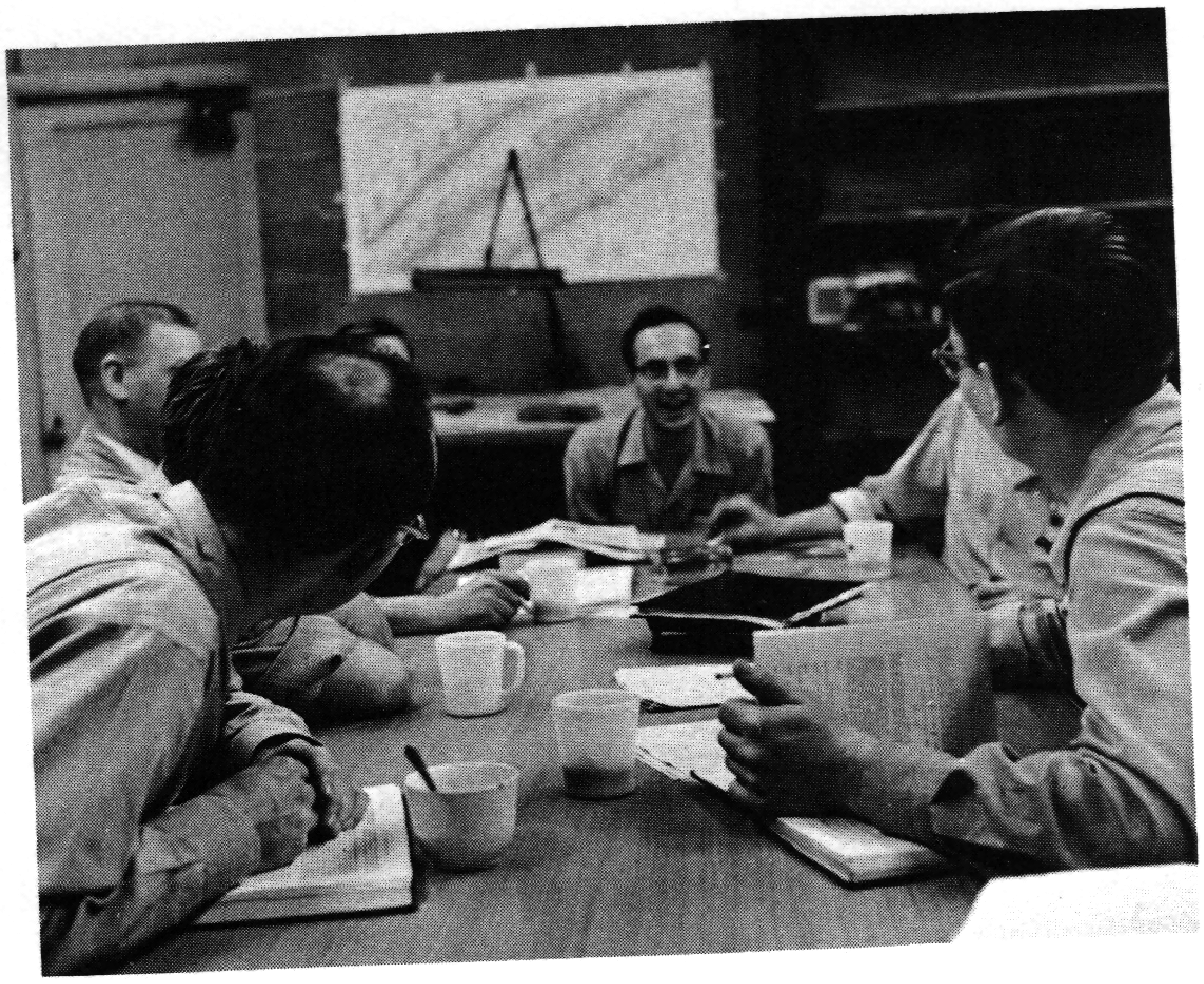


Figure 8. Social hour.

form. Halls, doorways, and the freight elevator should be adequate for the transport of such equipment into the place where it will be used. Opening and reconstructing exterior walls is expensive.

Social Facilities

Physics departments, like others, are composed of people with common interests. Unlike modern business offices, they do not have daily "coffee breaks," but it is the usual practice to have a weekly get-together of a social nature, often in connection with a colloquium address on some topic of timely interest. Refreshments are served. Sometimes wives attend. Such occasions foster a very desirable esprit-de-corps, but also have an educational function. "Shop talk" goes on among physicists very freely and there is perhaps no more fruitful source of pertinent information, stimulation, and ideas. Every physics department of even a modest size needs a room for such gatherings, equipped with a small adjacent serving pantry adequate for the preparation of coffee, tea, and the serving of cookies. The room can otherwise be used for reading, conferences, and the like.

CONCLUSION

It has been the purpose of this introductory chapter to call attention to the increasing physics research and teaching load requiring adequate building space, to suggest how the extent of space needs may be estimated, to explain the special characteristics of physics as they affect space requirements for teaching and research, and finally to outline briefly the kinds of facilities which should be provided in every good physics building. The remaining chapters are intended to offer more detailed and specific aid in planning the actual construction of a building that provides such facilities.

2. The Roles of Administration, Physics Staff, and Architect

INTRODUCTION

The construction of any new building requires the cooperation of a number of interested parties, and this is particularly true for a physics building on a college campus. Although the principal responsibility for producing a good building rests with the administration of the college and the architects that are selected, if the building is to satisfy its intended use the physics staff must accept the responsibility of assisting in its planning.

THE STEPS IN BUILDING

Table I shown on page 16, prepared by Nolen and Swinburne, Architects, of Philadelphia, summarizes the steps in designing and constructing a new building. There are three major stages in the process. The first is the planning stage. It requires the cooperative efforts of all interested parties and extends to about Step 16 in the table. During the second stage, working drawings are prepared and, after they are approved, the contract for construction is let, at Step 36 in the table. This stage is more straightforward and requires only occasional consultation with the physics staff. The final stage is that of construction, under the supervision of the architect, which ends when the completed building has been accepted.

PROGRAMMING

Definition of Terms

Programming is collecting the requirements for a building, communicating them to the architect, and overseeing their incorporation in the design of the building. In some cases, these needs are spelled out in such detail that the building, in fact, is designed long before the architect enters the picture, even to detailed floor plans with the specific location of all equipment and services. In other cases, the building reaches the stage of working drawings and specifications with little if any consultation with the user. Neither extreme is common or, in general, desirable, but useful buildings have been programmed in many different ways. However, to arrive at an efficient and economical building, there is no substitute for intimate collaboration between the architect and the user from the beginning, with each contributing new ideas, and carefully studying and constructively criticizing the suggestions of the other.

Programming should remain as simple as practicable to be most useful. John Lyon Reid, an architect well known for his contributions to secondary school design, has written:

> "(Programming) can be carried out most effectively when the effort remains simple; pro-

Table I. The Steps in Building

CLIENT	ARCHITECT	CLIENT AND ARCHITECT
1 Seeks architectural services		
		2 Preliminary conferences 3 Owner/Architect agreement 4 Establish building program 5 Set production time limits
	6 Program analysis 7 Schematic designs	
8 Approves schematic documents		
	9 Preliminary drawings 10 Preliminary specifications 11 Preliminary estimates	
		12 Conference on preliminaries
	13 Revisions to preliminaries	
14 Approves preliminary documents 15 Authorizes final documents 16 Approves special consultants, if any		
		SPECIAL: 17 25% of fee now payable
	18 Final working drawings	
		19 Conference on specifics
	20 Final specifications 21 Final estimates	
		22 Set construction time limit 23 Conference and review
	24 Revisions, if required	
		SPECIAL: 25 Review by City, State and Federal groups 26 Conference and acceptance
27 Approves final documents		
		SPECIAL: 28 50% of fee now payable 29 Select contractors for bidding
	30 Issues documents for bidding	
31 Receives bids		
		32 Bid tabulation and review
	33 Advises on contract award	
34 Awards contract		
	35 Assists in execution of contract	
36 Executes contract		
	37 Approves bonds and insurance	
38 Arranges for waiver of liens		
	39 Issues proceed letter to contractor	
		40 Field construction begins
	41 Supervises construction 42 Prepares field inspection reports 43 Reviews and approves shop drawings 44 Inspects and approves samples 45 Prepares monthly certificates	
46 Pays construction costs monthly		
		47 Review construction reports SPECIAL: Emergencies SPECIAL: Construction delays
	48 Prepares and signs change orders	
49 Countersigns change orders		
		SPECIAL: 50 25% of fee pro-rated
	51 Receives special guarantees from contractor 52 Makes final inspection	
53 Receives release of liens 54 Makes final payment 55 Accepts building 56 Assumes maintenance		
		57 Celebration

Chart prepared by Nolen & Swinburne, Architects.

gramming at its best is nothing more than face-to-face discussion between architect and user. The user should be expected to possess some knowledge of his needs and requirements, and should be able to offer a critical evaluation of plans and equipment. The architect, on the other hand, should be expected to possess some planning skill and a knowledge of construction and equipment . . . When I said that the most effective programming consists of face-to-face discussions between architects and users, I meant, of course, that these discussions must be supplemented by program material. The architects must have a program to work to and sketches must be developed to answer this program; but the face-to-face discussions are a fundamental necessity in developing and refining the plans for any educational facility. Too often legislators, administrators, and hecklers intrude between the architect and the user. A certain amount of this intrusion is necessary and perhaps even desirable, but the two key people in developing good school plans are the classroom teacher and the architect. Every effort should be made to increase the effectiveness of this relationship and to decrease the destruction of these intrusions."

Importance of Building Programming

Perhaps no other single step in the construction of a building is as important as programming, since it uniquely determines the use and usefulness of the building. Ample time must be allowed, and many administrators and physicists insist that the member of the department most responsible for programming a new building be relieved of his teaching duties while working on it. Many who learned of the demands on their time only after participating in programming suggest that a period of one year is not too much to allot to such an assignment.

Most architects are familiar with the importance of programming, and indeed on some other types of buildings they are accustomed to doing most of the programming themselves. In planning physics buildings and other highly specialized and technical facilities, however, the advice and assistance of the users play a vital role. Architects usually prefer to start from the needs of the user, with all the information necessary to arrive at one or more alternate solutions, rather than from the user's plans detailing the specific layout of the proposed building. The architect is then allowed more freedom to use his imagination and good judgment and may come up with some new solutions which would be well to consider.

The design should stem from the *functions* the building is to serve. The primary responsibility for defining these functions falls on the user, while the primary responsibility for designing a building to serve these functions falls on the architect. The key to successful programming is a critical, open-minded approach by all parties.

Information Needed for Programming

Effective programming calls for specific answers to specific questions. Here are some of the questions which both the architect and the user must face:

1. *How will the building be used?* What functions will it serve? What will be the proportion of instructional, research, and other activities?
2. *Who will use it?* How many occupants will it accommodate? What will be the proportion of faculty, students, staff, and visitors?
3. *What changes in its use can be anticipated?* How will the use of different areas change? How will enrollment changes alter the effectiveness of various parts?
4. *Which functions or activities are related, and which are not?* Are shop functions related to laboratory functions? Are office activities related to lecture hall activities?
5. *What will be the nature of the occupancy of different areas?* Where will the occupancy be transient, and where permanent? Which areas will be public, and which areas need have only very limited access?
6. *What will be the pattern of traffic?* Where will the traffic be most? How does the traffic from a large laboratory differ from the traffic from a lecture hall, for example?
7. *What services will be required?* Which activities or areas will need water, gas, air, vacuum, and different electric services?

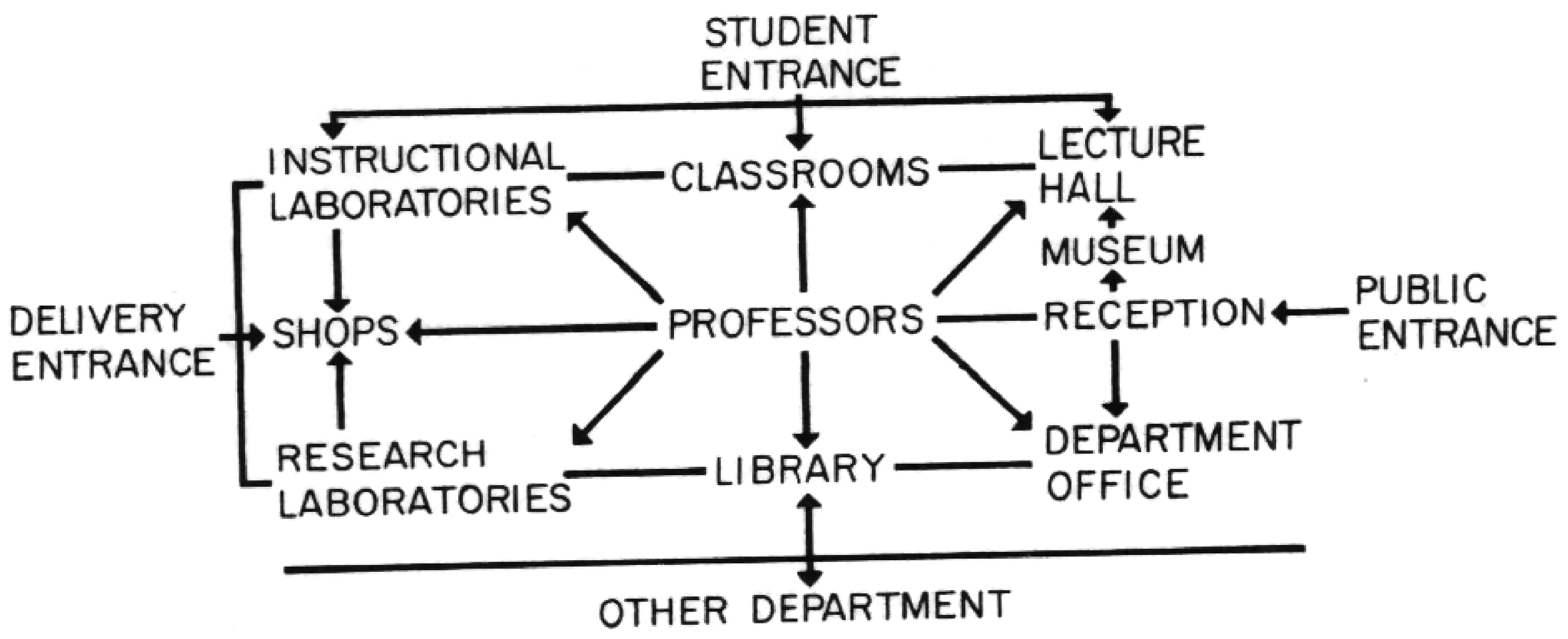


Figure 1. Functional plan of the physics area in a science building.

8. *What special requirements will be met?* Which activities or areas will need unusual cooling, heating, ventilating, filtering, shielding, lighting, or audio-visual facilities?

Since the answers to these questions determine how the building will be patterned, they should be carefully examined as part of the programming long before the architect begins drawings of the building. He needs to know the answers, which only the user can give him.

An example of one approach to programming is illustrated in Figure 1. This is a functional plan—not a layout—which evolved at one institution, during the programming of a physics area in a building devoted to instruction and research in the natural sciences. It was created primarily to show exactly how the different activities of the physics department are related (see question 4 above) and to indicate in general the pattern of traffic (see question 6 above). Its purpose was to locate these activities conveniently and efficiently, within the boundary conditions specified by the size and shape of the building. Unfortunately the size and shape are beyond the control of the user, since they are primarily determined by the funds and site available.

Central to the physics area are the permanent occupants, the professors, who need convenient access to all areas. At the left in Figure 1 is the delivery entrance for all shipments to the shops and laboratories. At the right is the public entrance through the reception area to the museum and lecture hall on one side, and to the department office on the other. At the top, students, who are generally transient, have easy access to instructional laboratories, classrooms, and the lecture hall. At the bottom is another science department in the same building, which shares the science library with physics and may even share research laboratories. This library complements the general library with a working collection of periodicals and books, primarily for advanced students and faculty, but it is accessible to all students although relatively far from the student entrance at the top.

The three entrances in Figure 1 are functionally separate. Traffic is simplified by locating the activities involving both the largest numbers of persons and the most transient persons, on the periphery of the building: all instructional areas, for example, empty to the outside. A single public entrance to the building is designed to reduce confusion for visitors unfamiliar with the building. The instructional laboratories and research laboratories have equal access to the shops for the construction, maintenance, and repair of equipment, and the faculty has direct access to all areas.

This plan may not be applicable to a junior college, where research activities may be very limited and a major delivery entrance to the shops quite unnecessary. Nor can it apply to an industrial laboratory which has no instructional functions. Furthermore, topological considerations make it impossible to adopt an ideal functional plan as a preliminary drawing for an actual building. Nevertheless the approach is a useful one in defining functions, communications, and traffic in a structure as complex as a physics building.

TYPICAL HISTORY

A short account of a typical but fictitious building will demonstrate one method of programming. It is not presented as a model, but only as an example. It furthermore avoids the two extremes described earlier, neither of which appears highly desirable; the user plays a most important role in programming a physics building, but his role is not that of the architect.

Coriolis College built its physics laboratory in 1900, a brick edifice of modest dimensions but impressive solidity. When it was completed it was the pride of the college, but the boast that it would "last forever" was heard less and less as the passing years revealed its basic shortcomings; it was too small and too inflexible to meet changing requirements. Although rooms could be subdivided, the load-bearing walls which bounded them fixed the maximum size once and for all. Maintenance and repair grew more and more expensive, and any new or expanded laboratory service was a major installation problem.

Talk of a new building began some 15 years ago, with hopeful remarks by the president, and members of the department began to meet occasionally to discuss what they wanted in it. A number of them accumulated notes, pictures, and sketches of features they wished to include in the new building, as well as clippings from newspapers and magazines on recently completed laboratories. Occasional visits to other institutions offered valuable opportunities to observe both the desirable and undesirable features of other buildings, to adopt their more successful designs and to avoid their pitfalls. However, their own professional experience more than any other single factor dictated their concept of the new building, in spite of the total inadequacy of their current facilities; a professor wanted a new room "just like the room I have now, except . . ." Carefully evaluated experience with their existing building assisted programming as a yardstick for comparing areas, for example, as well as providing a sizeable list of ideas.

One morning the president informed the chairman of the physics department that his patient waiting was over, the next building on the campus would be for physics; and asked how soon could the department make its needs known to the architect. Suddenly the pressure became one of time. A building committee was appointed to begin programming. Its membership was not limited to the physics department, but the department chairman was appointed chairman of the committee. Other members of the committee included another member of the department, one of the architects, and the plant superintendent who had many years of experience with campus buildings and services.

The chairman had the responsibility of critically reviewing not only the needs of his department, but also the proposed solutions from his colleagues. One of his problems was a professor who had designed his laboratory in the minutest detail, unaware that it would require custom-built furniture throughout and that his forthcoming retirement would make it obsolescent if not obsolete. Prejudices on matters such as chalkboards, as well as on other matters even more prosaic, had to be carefully sifted, and the architect consulted frequently on alternative solutions to specific problems, consistent both with the funds available and the technical requirements.

The architects for the new Coriolis physics building had designed schools and hospitals, but this was their first science building. They studied the plans of other science buildings typical of good modern practice, but relied most heavily on the advice of the physics department and the building committee. Sales engineers with specialized products presented sample layouts and specifications, which were invariably referred to the ultimate user for his recommendation. The architects had virtually the sole responsibility for estimating costs, and instead of vetoing particular features with the assertion that they were "too expensive," they informed the building committee of the approximate costs of the alternative solutions, pointing out that sometimes the most expensive solution to one problem could be compensated by a less expensive solution to another. The architects were also alert to the latest advances in architectural design, engineering, processes and materials, and in several cases suggested novel answers considerably more economical and often more efficient than conventional practice.

The building committee circulated a concise questionnaire to all members of the physics department, studied their responses, and after discussion summarized the essential features for the use of the architects. Throughout the programming, the college administration, confident in both its physics department and its architects, minimized its intrusions and gave the building committee both responsibility and authority for programming the building.

The first preliminary drawings were broadly schematic, and were circulated by the building committee for comment. The sketch of the exterior was discussed at length, but as it developed it bore little resemblance to the completed building. For public relations purposes, however, the sketch was indispensable, especially for display in connection with the campaign for funds. The preliminary drawings were extensively modified. A new estimate by the architects of the probable building cost per square foot led to some shrinkage in the floor area of the building, and it was decided to provide only one lecture hall, to be shared by other departments until the building could be enlarged. One member of the building committee insisted on detailed layouts of the contents of each room, showing the furniture and equipment proposed for each. Not only did this study demonstrate that in many cases less area was required, when the room was carefully planned, but also it became possible to adopt several standard sizes for offices, classrooms, and laboratories.

The final preliminary drawings afforded the last opportunity for major changes in the building, and were reviewed in detail by the entire department and the building committee. These drawings showed that a high degree of flexibility toward future changes had been incorporated, to minimize both the expense and the disruption of normal activities when an area was converted to another use. The locations of utilities and services were fixed, and the architects and engineers began the preparation of the detailed working drawings and specifications on which contractors were invited to bid.

The administration directed that the design of the building be "frozen" at this stage, and the working drawings were prepared by the architects with virtually no reference to the physics department. Occasional telephone calls decided minor technical details. The chairman of the building committee insisted on reviewing the working drawings, and indeed identified several oversights that would have been excessively expensive to correct at the last minute. A few hours checking drawings is analogous to reading proof for a manuscript, but undiscovered building errors which find their way into the finished building cannot be remedied by printing an "erratum"; they may be difficult or impossible to remedy, and will live instead in the building to plague and sometimes haunt the users for a long time.

Several contractors were invited to submit bids for the building, in sealed envelopes, and opening the bids was an exciting event for the building committee and the administration. The architect and physics department chairman each felt he had the most at stake, but this feeling was shared by the contractors, since they were backing their bids with their own money and reputations. At the beginning the administration had limited the size of the building by the funds available, and had budgeted an increase in the building cost between the initial figure and the actual completion of construction two years later, due to growing costs of materials and labor. In this case the successful bid was slightly below all estimates, and left a small margin to help purchase badly needed equipment. The closeness of bidding and the amounts of the lower bids reflected directly on the professional ability of the architect, and the building committee was satisfied with the outcome.

When the contract was let, the architect became responsible for overseeing the job and for insuring that the plans and specifications were met. The chairman of the building committee accompanied the architect's representative for periodic inspections. Subsequent changes were transmitted to the contractor through the building superintendent. Errors which required correction were very few.

Construction was completed on schedule, and the physics department moved into its new quarters during the following spring vacation. The building was found to satisfy quite completely the needs of the department and to have the adaptability required to meet changing needs.

3. The Building

INTRODUCTION

Most architects, as well as their clients, approach the design of a physics building as a first-time experience. Many details of design can be, and should be, shared between the architect and the physics staff. Special problems arise because a physics building is more complex than most other college buildings. It must satisfy some rather specialized mechanical and electrical requirements. Furthermore, it must be able to accommodate to changes which are likewise beyond those that can be anticipated for most other campus buildings.

DESIGN OF THE PHYSICS BUILDING

Flexibility

In present-day discussions concerning educational facilities, the concept of flexibility is receiving universal approval, and sometimes without much objective questioning of just what is meant by the term. Flexibility is defined as "adaptability" in a paper presented by E. D. J. Mathews at an architectural symposium on laboratory design held recently in London.[1] He goes on to say that adaptability in a building is a "provision in the design of the structure, services, equipment and finishes which will permit the original allocation of space and internal arrangement to be changed—adapted—when the building is in use with a minimum of disturbance. I exclude the word 'cost' in this definition because, although related to adaptability, it does not affect the principle. It affects the extent."

There is general agreement on the need for flexibility in a physics building but disagreement as to just how and to what degree flexibility is best introduced. Costs must be considered—not only first cost, but overall long-time costs as well. There are ways in which changes in a building, or its need for expansion, can be anticipated and planned for in initial design with little or no increase in first cost. This is simply good planning, and is the kind of flexibility that can never be overdone. On the other hand, inclusion of highly repetitive mechanical and electrical services, which may never be used, or the lavish use of movable walls and partitions beyond the extent of actual need can definitely be an extravagance. The fact that many of our older science buildings could be described as bastions of inflexibility, yet have served rather well for many years, may not be evidence against current needs for flexibility, but it certainly confounds the theory that the *teaching* of science demands flexibility and cannot be accomplished within rigid facilities. The rapidly increasing space being given to research is the single new factor which now makes it necessary to give greater consideration to the needs for flexibility.

Research needs facilities which can be

adapted to changing needs. Although a classroom building may not need change for years, a research laboratory may require new services, and occasionally partitions may have to be moved. Methods of accomplishing these changes must be considered in initial design. However, it should be emphasized that these requirements are much less severe for research in colleges and universities than for industrial research laboratories.

A study of alternative designs from the point of view of maintenance can be as important in reducing long-time costs as designing for flexibility. Building operation is an expensive activity. For example, the cost of heating and cooling air can be unnecessarily high when insufficient thought has been given to properly sizing and controlling heating, ventilating, and air conditioning systems. Hidden costs, though almost impossible to determine, may be even more significant. These would include lost time and inefficiency, absences or delays brought on by inadequate or uncomfortable facilities.

Costs

The first cost of a new building remains a most important figure, and because it is both large and knowable, more attention is usually focused on it than on subsequent costs. The reported cost of construction accompanies the building plans for each of the buildings described in Chapter 4. Table I gives a breakdown of construction costs for a college physics building built in the northeastern United States in 1960. All such figures are useful for preliminary estimates only and cannot be transferred to a proposed building without knowing detailed specifications. They should be thought of as rough indexes of cost only.

Furthermore, geographic location must be considered. The "Construction Cost Indexes" published regularly by the F. W. Dodge Corporation in *Engineering News Record* and *Architectural Record* enable comparison of costs of construction between various regions of the United States.

Table I. Cost of a Typical College Physics Building, 1960

	Cost per Square Foot of Gross Building Area
General Construction	$11.84
Plumbing	2.76
Heating, Ventilating, Air Conditioning*	5.28
Electrical	2.46
Elevators	0.29
Laboratory Equipment	2.17
TOTAL	$24.80

* Two dollars should be added to cover extra heating cost for either a boiler in the building or a pro-rated portion of the campus central boiler plant.

Costs shown here are for a physics building in the northeastern United States, constructed in 1960, and do not include site work, landscaping, architects' fees, or special laboratory equipment. Construction for this example is multi-story (3-story) concrete frame with concrete floors, and masonry cavity panel walls.

Site Planning and the Master Plan

Site planning not only locates the building but often influences the size and form of the building. As with our cities which have in many cases "painted themselves into a corner," our campuses with their similar problems of scarcity of building sites, building expansion, and automobile parking face many problems in planning. As a tool to help solve these problems, foremost is a campus master plan. This should not be a theoretical plan, filed away in the department of physical plant, but an active, growing, working plan. To emphasize the importance of a master plan, two typical examples may be cited where the lack of a realistic master plan has left physics buildings with definite problems.

The first example has a very formal campus plan—a scheme of many years standing. A recently completed physics building was placed symmetrically to balance a three-story classroom building built earlier. The exterior architecture for the two buildings is practically identical. Because the physics building needed a much larger amount of space than the other building, a basement and a subbasement were provided. Not only is access to shops located in the subbasement awkward, but much more significantly, the symmetry above ground makes future building expansion impossible. Furthermore, the location and the requirement of symmetry do not allow the building to have a back side—a service area with a receiving dock—to serve the utilitarian needs of the building. The master plan did not recognize realistically either the size or specialized requirements of a physics building.

In the second example it became necessary to double the area of the physics building and the only direction available was at one end of the existing three-story building. However, a large two-story lecture hall blocked this end. There is thus, unfortunately, no direct access between the original building and the addition on the first and second floors. Building users must either go outside to get around the lecture hall or cross at the basement or third-floor levels. Plans for future expansion were evidently not included in the design of the building.

The Single-Story versus the Multi-Story Building

When space permits, one- and two-story buildings seem to offer more possibilities for expansion than higher rise buildings. This advantage, as so many in architecture, has been first recognized in industrial buildings. It is significant that many large industrial concerns are adopting what are proudly termed "campus plans," where space permits, and often go to considerable effort to find new locations where old sites do not permit the required expansion. By campus plan is usually meant a spread-out, articulate site plan with buildings sized and situated according to needs, and with the open space between buildings studied for landscaping, walks, parking, and sometimes recreation areas—all as much a part of the planning scheme as the buildings themselves. Symmetry is not ruled out in such planning, but symmetry gives way to use. Planning based strictly upon use is less likely to produce either identical buildings or formalism.

The multi-story scheme is typical of most science buildings on college and university campuses. Besides requiring less site area than a single-story structure, a multi-story building requires less outside surface for a given volume. An additional advantage includes the greater efficiency in layout of electrical and mechanical services possible in a multi-story structure. Where toilet room fixtures, sinks, services, outlets and drains occur repetitively, there are advantages in stacking them one above the other. Shorter pipe and duct runs are required. Besides a reduction in initial cost, shorter runs result in less frictional loss for fluids and less voltage drop in the case of electrical runs. However, multi-story schemes need stairways, elevators, and increased fireproof construction, and these add to initial cost. To provide for future additions, the multi-story building is sometimes given sufficient strength to accommodate future floors. The shop wing at the University of Florida (Chapter 4, Figure 3) is framed to take additional construction overhead. A one-story building is less often designed to take a future floor.

Planning Aids

In planning a new physics building, other institutions should be visited. Such visits can be made to serve best if supplemented by notes, sketches, and photographs. One should learn how the facilities are used; what is useful at one institution may not be useful at another. It is particularly important to get the evaluation of facilities by those who use them. Furthermore, valuable lessons will be learned on things to avoid as well as on what to emulate.

Published laboratory and classroom standards are additional aids to planning. Here, a note of caution is in order—codifying can lead to blindly copying another's design—standards should serve as guides and not as particular solutions. Many universities set standards listing the maximum amount of floor areas to be allocated to certain offices; lecture room areas are computed on a per seat basis; laboratory areas are determined on a work place basis, et cetera. The note of caution applies here again. Too many "standards," originally intended as minimums, have been used to establish design maximums (and vice versa).

Further aids during the early stages of planning include the use of furniture and equipment templates. In all space planning, working to scale is essential. To draw and redraw furniture and equipment to scale is very tedious and time consuming. The use of templates not only enables one to check clearances but, what is more important, it opens the imagination to the consideration of various possible arrangements.

Some planners in the early stages avoid sketches which suggest actual physical appearance or arrangement, and prefer to deal in "principles," using chart type diagrams to study organization and flow. They feel this to be a more objective study. However, for most persons, drawings to scale even in the early stages provide the simplest and most direct approach. Drawings should be kept simple, hence "fluid," so that many alternates will be tried.

Valuable reference information is available in many of the books and articles given in the bibliography at the end of this book. An article of particular relevance to this chapter is "Planning the Scientific Laboratory" by Charles S. Haines.[2]

The Planning Module

Early in the planning stages for a building, building areas may be laid out on paper to scale in convenient unit areas, or planning modules, such as, for example, 4-by-4-foot squares, 16-foot bays, et cetra. Such a module is of great help to architect and layman alike. It provides members of a group working together on plans for a new building with a common unit which, through repeated use, soon becomes very real. Planning modules may reflect a proposed column spacing but they do not necessarily need to do so. Related to this ordered approach is a nationwide trend toward modular coordination through building products standardized on the basis of a 4-inch module. This has now been done with concrete and tile masonry, windows, doors, flooring, acoustical tile, wall board, and many other stock fabricated items. It allows a systematic approach to design which can result in simpler dimensioning of drawings. It also results in greatly reduced cutting and waste of material in construction. The planning module recommended here, however, is not dependent on conforming to any special materials standardization. It is recommended simply as a very useful tool which may or may not affect the construction module.

Space Distribution and Circulation within the Building

The size and location of a physics building is largely determined by the master plan of the campus and by budget considerations. The space distribution within the building is determined by the requirements of individual areas as described in Chapter 2, the space required for each function to be served and its need for being near other areas. In this connection, circulation within the building enters the picture, both for the movement of materials and the traffic of individuals. Factors which affect the locations of lecture room, classrooms, laboratories, shops and receiving areas are discussed in subsequent chapters. If an elevator is to be installed, it should be located near the receiving area and the shop where the primary function of the elevator for moving freight will be best served. If it is located so that it is under the surveillance of the main office or shop, its excessive use by students can be discouraged.

Corridor and stairway layouts are influenced by the requirements of room size. Frequently the rooms of varying size required by a physics building can be distributed most economically if the corridors in the building

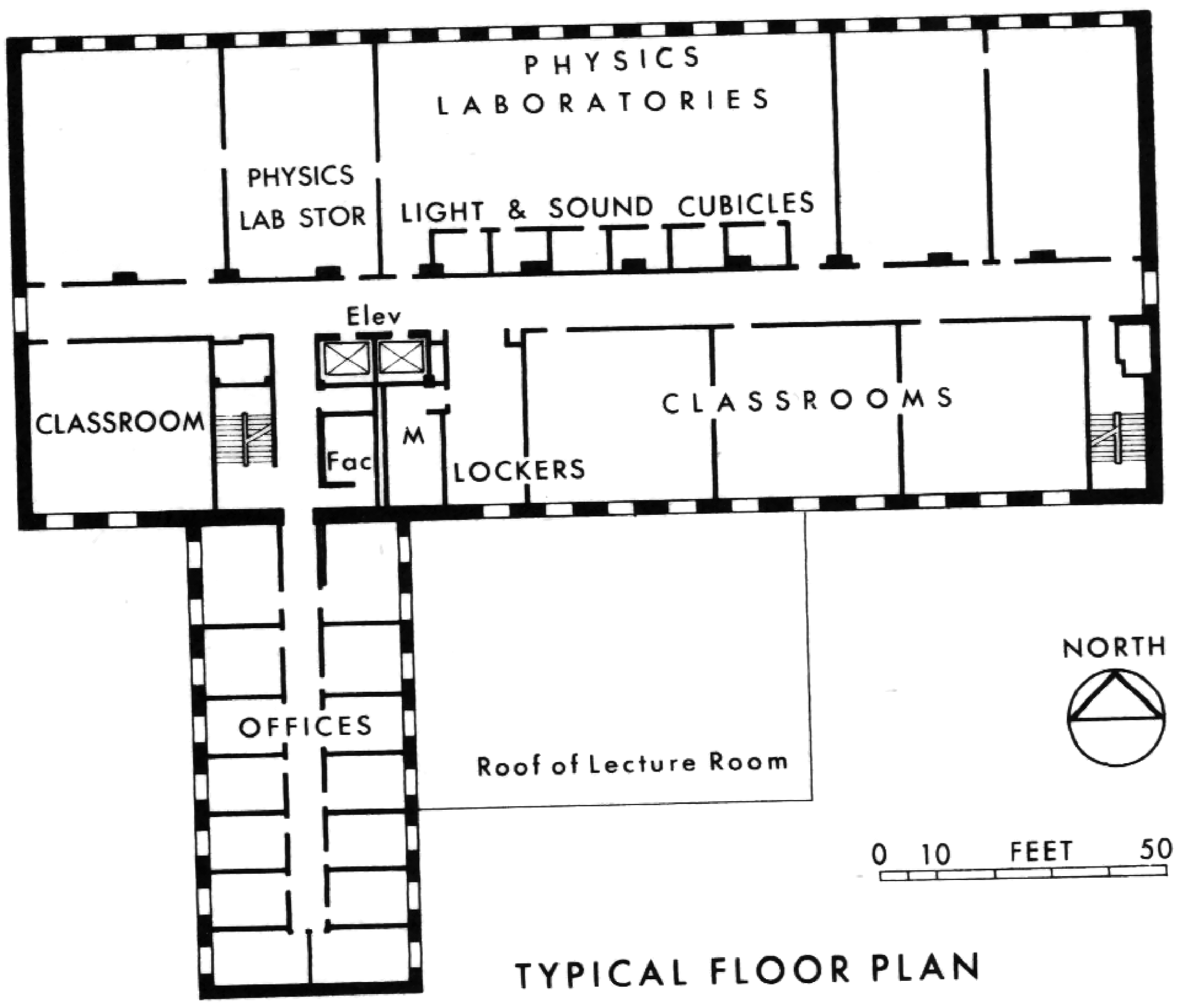
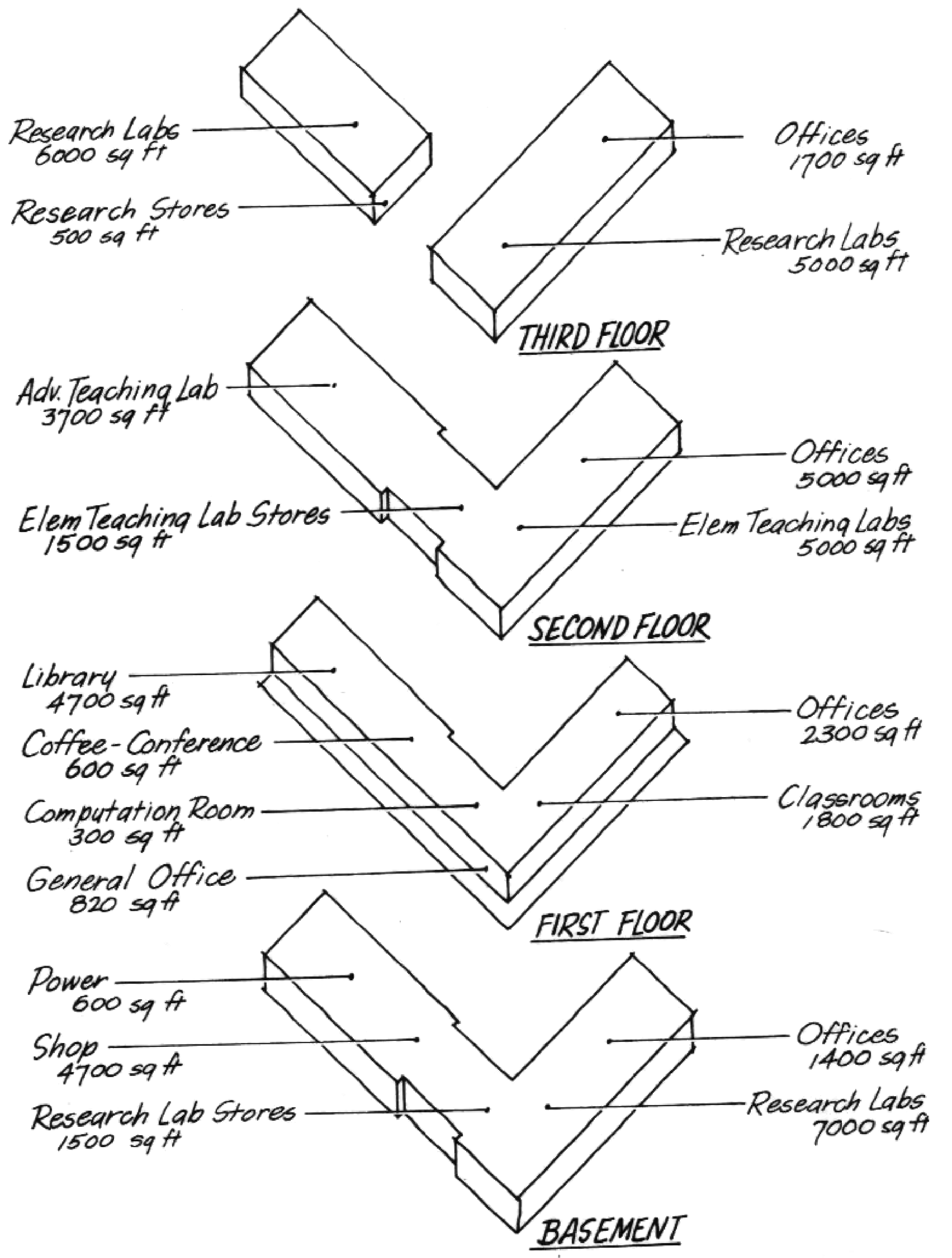

PHYSICS
LABORATORIES
PHYSICS LAB STOR
LIGHT & SOUND CUBICLES
Elev
CLASSROOM
CLASSROOMS
Fac
M
LOCKERS
OFFICES
Roof of Lecture Room
NORTH
0 10 FEET 50
TYPICAL FLOOR PLAN

Figure 1. Typical floor of the new six-floor Engineering Building for Cooper Union. Note that the offices are housed in a separate wing. Voorhees, Walker, Smith, Smith and Haines, Architects, New York.

are off center. Seminar rooms, offices and other small rooms require less depth than laboratories and classrooms. The principal risers for mechanical and electrical services then need to be installed only on the laboratory side of the corridor.

Where a building is to have a large number of offices it may be desirable to design a separate wing especially for offices and other small rooms, as has been done for the new Cooper Union Science and Engineering Building (Figure 1). Such a scheme provides several economies in construction, though it does lack a degree of flexibility in that the space in an office wing cannot readily be assigned to functions requiring large rooms. One saving results from the fact that only a minimum of electrical and mechanical services need be installed in an office wing. At the same time, the services required in other areas of the building can be more highly concentrated. The lower floor loading coupled with the shorter spans permitted in an office wing can save on structural costs. Furthermore, both the structural column bay and the width of the office wing can be suited to the office module, often with more modest spans and nearly always with better proportioned offices.

Figure 2 is a reproduction of a preliminary study of space assignment for the new physics building at Stanford University. The original sketch was made by the Stanford Planning Office. This is *not* a design for the building itself but rather illustrates a method of studying the relationship between the various functions of the building. No lecture rooms are shown since these are already provided in the recently completed Lecture Hall Building (Chapter 5, Figure 1) which is adjacent to the site selected for the physics building. The ell-shape of the building was predicated on site requirements.


Research Labs 6000 sq ft
Research Stores 500 sq ft
Offices 1700 sq ft
Research Labs 5000 sq ft
THIRD FLOOR
Adv. Teaching Lab 3700 sq ft
Offices 5000 sq ft
Elem Teaching Lab Stores 1500 sq ft
Elem Teaching Labs 5000 sq ft
SECOND FLOOR
Library 4700 sq ft
Offices 2300 sq ft
Coffee-Conference 600 sq ft
Computation Room 300 sq ft
Classrooms 1800 sq ft
General Office 820 sq ft
FIRST FLOOR
Power 600 sq ft
Offices 1400 sq ft
Shop 4700 sq ft
Research Lab Stores 1500 sq ft
Research Labs 7000 sq ft
BASEMENT

FUNCTION	PROGRAMMED	SUPPLIED
Teaching Lab-Elem	5000	5000
" " -Adv	3700	3000
Research Labs	18000	18000
Offices - 86 @ 150 sq ft	12900	10400
General Office	820	820
Comp Room	300	300
Coffee-Conf	600	600
Classrooms	1800	1800
Shop	4500	4500
Power Room	600	600
Library	4700	4700
Stockrooms	3500	3500
TOTAL (Net)	56420	53220

Figure 2. Preliminary space arrangement study for proposed physics building. Stanford University Planning Office.

Table II

LE CONTE ANNEX - PHYSICS

	USE OF ROOM	KEY	ASSIGN OCCUPTS MAX	NO OF ROOMS	SQ FT PER ROOM	SQ FEET TOTAL	TOTAL AREA PER DEPT	HOURS UTILIZ PER WK	LOCATION & RELATIONSHIP TO OTHER FACILITIES	HTG & VENTIL'G	ELEC & COMMUNIC	PLUMBING	BUILT-IN EQUIP	MOVABLE EQUIP	REMARKS
EXPERIMENTAL RESEARCH	2 MW - GENERATOR & CONTROLS	AA	1/5	1	1500	1500		168	LOWEST FLOOR GEN IN PIT NR AB	NORMAL	2 MW POWER MAG, BUS BAR IC & TEL	GAS AIR WATER SINK	CHALK & TACKBOARDS	1 EXEC DESK W/CH 1 FILE CAB	SOUND ISOLATION REQ'D
	HEAT EXCHANGERS & PUMPS	AB	1/5	1	400	400		168	CLOSE TO AA AI30 & AG	NORMAL	OPERATE HEAT EXCH IC & TEL	SINK WATER & WASTE LINE	CHALK & TACKBOARD 3 HEAT EXCHRS W/PUMPS FOR MAGNETIC COOLING		SOUND ISOLATION REQ'D
	COOLING TOWER	AC	0/?	1	1600	1600		168	BLDG ATTIC FOR PROPER HEAT EXCH.	NORMAL	SERVICE TO OP COOLING UNIT	300 GPM PRESS TO 120 PSI	CHALK & TACKBOARD		
	HELIUM RECOVERY	AD	?/?	2	300	600		168	NEAR LOW TEMP LABS	NORMAL	* IC & TEL	GAS WATER AIR & WASTE LINE	CHALK & TACKBOARD		HAZARDOUS SOUND ISOLATION REQ'D
	COMPUTER	AE	?/10	1	1400	1400		90	LOWER FLOORS INSIDE RM NEAR AF	AIR CONDITION	FOR COMPUTER IC & TEL	WATER AIR & WASTE LINE	CHALK & TACKBOARD	IBM 650 - CARD FILE CABS(12 2 LIB TABLES · 4 FILE CABS	SOUND ISOLATION REQ'D
	COMPUTER SERVICE	AF	2/4	1	200	200		90	LOW NEAR AE	NORMAL			CHALK & TACKBOARD	2 DESKS - 2 BKCASES LIB TABLE - 2 FILE CABS	
	MEGAWATT MAGNET	AG	4/10	4	300	1200		168	LOW NEAR AA - AB	NORMAL	* IC & TEL	GAS AIR VAC'M FLR DRN ACID TRAP W/TR SINK 300 GPM 120 PSI	CHALK & TACKBOARD & LAB TABLES PUMPS	BOOKCASE	ACCOUSTICAL CEILING
	SPECTROSCOPY	AH	3/10	1	600	600		168	LOW	NORMAL	*	AIR GAS VAC'M WATER ACID TRAP FLR DRN HOT COLD	CHALK & TACKBOARD	DESK BOOKCASE BITTER ZEEMAN MAG	
	DARKROOMS	AI-1	0/								*				
	RESEARCH EXPERIMENTAL PHYSICS	AI-2a	4/10	12	300	3600		168	LOWER FLOOR	NORMAL	* IC & TEL	GAS AIR VAC'M WATER SINK ACID TRAP FLOOR DRAIN	CHALK & TACKBOARD 2 LAB TABLES	BOOKCASE CHAIR	ACCOUSTICAL CEILING
	RESEARCH EXPERIMENTAL PHYSICS	AI-2b	4/10	15	300	4500		168	LOWER FLOOR	NORMAL	* IC & TEL	GAS AIR VAC'M WATER SINK ACID TRAP FLOOR DRAIN	CHALK & TACKBOARD 2 LAB TABLES PUMP	BOOKCASE	ACCOUSTICAL CEILING
	RESEARCH EXPERIMENTAL PHYSICS	AI-2c	4/10	10	300	3000		168	LOWER FLOOR	NORMAL	IC & TEL	GAS AIR VAC'M WATER SINK ACID TRAP FLOOR DRN	CHALK & TACKBOARD 2 LAB TABLES PUMPS	BOOKCASE	ACCOUSTICAL CEILING
	ATOMIC CLOCK TIME STANDARD	AI-2d	2/10	1	300	300		168	LOWER FLOOR	AIR CONDITIONED THERMOSTAT	* IC & TEL	GAS AIR WATER ACID TRAP SINK VAC'M	LAB TABLE		
	RESEARCH SAMPLE PREPARATION	AI-2e	6/10	4	300	1200		168	LOWER FLOOR ONE FOR EACH FLOOR 2b, 1b, 1 & 2	NORMAL	*	GAS AIR WATER FLOOR DRAIN	CHEM TABLE UC FUME HD W/SINK LAB TABLE	BOOKCASE CHEM CAB	
	RESEARCH SOLID STATE PHYSICS	AI-2f	4/10	3	300	900		168	ATTIC	SPECIAL FOR LIQUID HYDROGEN	* IC & TEL	GAS AIR VAC'M WATER SINK ACID TRAP FLOOR DRAIN	CHALK & TACKBOARD	SPARK PROOF GEARS & FLOORING	ACCOUSTICAL CEILING
	RESEARCH HIGH FREQUENCY	AI-3	4/10	6	400	2700		168	LOWER FLOOR	NORMAL	* IC & TEL	AIR GAS VAC'M SINK ACID TRAP	CHALK & TACKBOARDS 2 LAB TABLES	1 BOOKCASE	ACCOUSTICAL CEILING
	RESEARCH NUCLEAR RESONANCE	AI-4a	4/10	2	600	1200		168	LOWER FLOOR CLOSE TO AI-4b	NORMAL	* VARIAN MAG FREQ. COUNTER IC & TEL	AIR GAS VAC'M WATER SINK ACID TRAP FLR DRN	CHALK & TACKBOARD 2 LAB TABLES	DESK BOOKCASE CHAIR STOOLS	ACCOUSTICAL CEILING
	RESEARCH NUCLEAR RESONANCE	AI4b	5/10	1	600	600		168	LOWER FLOOR CLOSE TO AI-4a	NORMAL	* IC & TEL	AIR GAS VAC'M WATER SINK ACID TRAP FLOOR DRN	CHALK & TACKBOARD		ACCOUSTICAL CEILING
	RESEARCH COMPUTATIONAL WORK	AJ-1	3/8	10	200	2000		50	EVENLY DISTRIBUTED WITH RESPECT TO LAB SPACES	NORMAL	110 VOLT IC & TEL	NONE	CHALK & TACKBOARD	3 DESKS - 3 BOOKCASES 2 SIDECHAIRS	
	RESEARCH COMPUTATIONAL WORK	AJ-2	2/4	20	100	2000		50	EVENLY DISTRIBUTED WITH RESPECT TO LAB SPACES	NORMAL	110 VOLT IC & TEL	NONE	CHALK & TACKBOARD	2 DESKS - 2 BOOKCASES 2 SIDECHAIRS	
	SUBTOTAL						29500								
THEORETICAL RESEARCH	FACULTY OFFICE RESEARCH	BA-1	2/5	5	160	800		50	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTLET & CONVEN IC & TEL	NONE	CHALK & TACKBOARD	2 DSK & CHR - MET TABLE - 3 BKC'SS 2 FILE CABS 2 SIDE CHRS	
	FACULTY OFFICE RESEARCH	BA-2	1/5	15	160	2400		50	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTL & CONVEN IC & TEL	NONE	CHALK & TACKBOARD	1 DSK & CHR - TABLE 2 CHRS 2 FILE CABS - 3 BOOKC'SS	
	VISITING STAFF	BB	1/5	4	160	640		50	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTL & CONVEN IC & TEL	NONE	CHALK & TACKBOARD	1 DSK & CHR - TABLE - 2 CHRS 3 BOOKCASES 1 FILE CAB	
	POST DOCTORAL RESEARCH	BC	2/8	6	204	1124		50	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTL & CONVEN IC & TEL	NONE	CHALK & TACKBOARD	2 DSK & CHR - TABLE - 2 SIDE CHRS - 1 FILE CAB - 3 BKCASES	
	FACULTY RESEARCH	BD-1	40/10	1	300	300		35	UPPER FLOOR NEAR LIBRARY	NORMAL	OUTL ON PROJ'TR IC & TEL	NONE	CHALK & TACKBOARD	1 DESK & CHR - 8 SEMINAR CHRS - & LIB TABLES	
	FACULTY RESEARCH	BD-2	40/6	1	200	200		35	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTL CONVEN IC & TEL	NONE	CHALK & TACKBOARD	1 DESK & CHR - 10 SEMINAR CHRS - 2 LIB TABLES	
	SCIENTIFIC WORKS STORAGE	BE	1/4	1	200	200		60	UPPER FLOOR NEAR LIBRARY	NORMAL	CONVEN THERMOF POWER STAPLER	NONE	TACKBOARD	LIB TABLE SIDE CHAIR	
	GRAD STUDENTS TEACHING ASST	BF-1	2/4	25	96	2400		60	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTL IC & TEL	NONE	CHALK & TACKBOARD	2 DESK & CHR - TABLE - 1 SIDE CHR - 2 BOOKCASES	
	GRAD STUDENT RESEARCH	BF-2	1/2	50	49	2450		50	UPPER FLOOR NEAR LIBRARY	NORMAL	CONVEN IC & TEL	NONE	CHALK & TACKBOARD	1 DESK & CHAIR 1 SIDE CHAIR	
	GRAD STUDENT RESEARCH	BF-3	3/6	4	200	800		50	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTL CONVEN IC & TEL	NONE	CHALK & TACKBOARD	3 DESK & CHR - 3 SIDECHR 1 BOOKCASE	
	GRAD STUDENT RESEARCH	BF-4	4/10	2	300	600		50	UPPER FLOOR NEAR LIBRARY	NORMAL	CLOCK OUTL CONVEN IC & TEL	NONE	CHALK & TACKBOARD	4 DESK & CHR - 6 SIDECHR 1 BOOKCASE	
	SUBTOTAL						11914								
CLASS ROOMS	LECTURE DEMONSTRATION	CA	1000/150	1	1500	1500		30	GROUND LEVEL NEAR EXISTING PREP ROOMS	AIR CONDITION	** CLOCK TV PICK-UP & PROJ SCREEN PA SYSTEM	GAS AIR WATER VAC'M SINK IN DEM TABLE	SLDG CHKBD COV'G ENT. FRT TACKBD - DEMON TABLE	1 PROJECTOR & STAND 150 SEATS	ACCOUSTICAL TRTMENT
	TEACHING SEMINARS	GA	125/25	5	280	1400		15	UPPER FLOOR ACCESSIBILITY	NORMAL	CLOCK OUTL	NONE	EXTENSIVE CHALKBOARD TACKBOARD	25 SEMINAR SEATS LECT TABLE - STRT CHR	
	SUBTOTAL						2900								
ADMINISTRATION	UNDERGRAD (ADMINISTRATION)	DA	5/25	1	900	900		45	NEAR EXISTING ADMINIS OFFICES IN LE CONTE	NORMAL	2 CLOCK OUTLS ELEC TYPE IC & TEL	NONE	TACKBOARD	5 DSK & CHR · 1 CT CAB 3 TABLES 5 BKC'S 5 ROL TABLS 10 CHRS & FILE CABS	
	STORAGE PHYSICS RESEARCH	DB	1/4	1	200	200		60	UPPER FLOOR NEAR LIBRARY & ADMINIS	NORMAL	NONE	NONE	TACKBOARD - BUILT-IN SHELVING	1 LIB TABLE 1 STR CHR	
	RECORDS STG	DC	0/2	1	152	152		50	UPPER FLOOR NEAR ADMINIS OFFICE	NORMAL	NONE	NONE	TACKBOARD - BUILT-IN CABINET FOR SUPPLIES	10 FILE CABS LIB TABLE CHAIR	
	SECRETARIES	DD	?/4	5	120	600		45	UPPER FLOOR NEAR ADMINIS OFFICE	NORMAL		NONE			
	MAIL	DE	0/4	1	100	100		50	UPPER FLOOR NEAR ADMINIS OFFICE	NORMAL		NONE	TACKBOARD BUILT IN MAIL COVES		
	SUBTOTAL						1952								
SHOPS	MECHANICAL SHOP	EA	6/12	1	2000	2000		50	GROUND LEVEL TO CONNECT W/EXISTING SHOPS	NORMAL	POWER FOR HVY MACH CLOCK IC & TEL	GAS AIR VAC'M WATER SINK FLOOR DRN	TACKBOARD	1 DSK & CHR 1 ENGIN LATHE 12" 1 DRILL PRESS 48" 1 DRFTG TABL	
	ELECTRICAL SHOP	EB	4/10	1	1250	1250		50	NEAR EXISTING MECHANICAL SHOP	AIR CONDITION	* CLOCK OUTL IC & TEL		CHALK & TACKBOARD	1 DSK & CHR 1 DRFT TABL 1 BKCASE 1 FILE CAB 4 STOOLS	
	SUBTOTAL						3250								
GROUNDS & BLDGS	JANITOR'S CLOSET	X-A	0/1	8	60	480			1 - EACH FLOOR PREFERABLY NEAR ELEV	NONE		WATER SINK H&C FLOOR DRN	SHELVING HANGER STRIP	1 LADDER 1 CUSTODIANS CART	WAINSCOTS & FLOORS CER TILE OR EQUAL
	CUSTODIAL OFFICE	X-B	4/4	1	200	200			GRADE LEVEL NEAR DELIVERY	NORMAL					
	CUSTODIAL SUPPLIES	X-C	0/4	1	300	300		168	GRADE LEVEL NEAR DELIVERY	NORMAL					
	TRASH		/												
	SUBTOTAL						980								
OFFICES	STAFF OFFICE	IA	1/4	10	120	1200		50	UPPER CENTRAL	NORMAL	CLOCK OUTL CONVEN IC & TEL	NONE	CHALK & TACKBOARD	1 DSK & CHR 1 COSTUMER 3 BKC'S 1 TABL 1 FILE CAB 2 CHRS	
	SUBTOTAL						1200								
TEACH LABS	LABORATORY (EXPANSION-110C-D)	HA	80/40	1	1200	1200		12	ADJ TO EXISTING LABS	NORMAL	*** CLOCK OUT SPEC ELEC IC & TEL	GAS AIR VAC'M WATER SINK ACID TRAP FLOOR DRN	CHALK & TACKBOARD 12 DOUBLE LAB TABLES	40 STOOLS · 4 VAC'M PUMPS 2 BKC'S 1 DSK & CHR 1 FILE CAB	
	EXPERIMENTAL OPTICS	HB	80/40	1	1200	1200		12	NO SPECIAL PREF INDICATED	NORMAL	CLOCK OUTL SPEC ELEC CHNLS IC & TEL	GAS AIR WATER VAC'M SINK ACID TRAP FLOOR DRN	CHALK & T'KBD ALCOVE FOR CAMRA OBSCURA 12 DOUB LAB TABLS	40 STOOLS	
	SUBTOTAL						2400								
SEMINARS	GRAD STUDENT SEMINAR	FA	300/50	1	1000	1000		20	UPPER FLOORS GENERAL ACCESS	NORMAL	CLOCK OUTLET CONVENIENCE	GAS AIR WATER SINK IN DEM TABLE	CHALK & TACKBOARD SCREEN	50 SEMINAR SEATS	ACCOUSTICAL CEILING
	FACULTY SEMINAR	FB	50/40	1	560	560		20	UPPER FLOORS GENERAL ACCESS	NORMAL	CLOCK OUTL CONVEN IC & TEL	GAS AIR WATER SINK IN DEM TABLE	CHALK & TACKBOARD SCREEN	2 10' COUCHES 4 SETTEE 4 TABLS 4 7' COUCHES 10 CLUB CHRS	
	SUBTOTAL						1560								
BLDG	GRAND TOTAL						55,656								

SHEET 1 OF ONE

FILE NO.

DATE SEPT 15, 1959

BUILDING OR PROJECT

CAMPUS

SCALE

SHEET TITLE

DRAWN CHECKED APPROVED

UNIVERSITY OF CALIFORNIA
OFFICE OF ARCHITECTS AND ENGINEERS
BERKELEY CAMPUS BERKELEY, CALIFORNIA

REFERENCES

NO. DATE DESCRIPTION BY APPD
REVISIONS

Table II is an example of a more detailed study of space distribution. It presents a detailed analysis of the space needs of individual areas for the proposed LeConte Annex—a second addition to the LeConte Physics Building at the University of California at

Berkeley. (The first addition is shown in Chapter 4, Figure 1). As can be inferred from the Table, the Annex will principally house research activities.

One question concerning space assignment that always comes up for a building that is to house more than one department is which floor or floors the various departments should occupy. One argument goes something like this: Physics is often concerned with experiments requiring freedom from vibration; hence, the physics department should be on the ground and lower floors; chemistry is concerned with experiments many of which make fumes; hence, for ventilation requirements, the chemistry department should be on the top floor or floors. There is nothing fundamentally wrong with this logic, but it should be pointed out that it is an oversimplification, and by not weighing some other considerations attention may be diverted from other solutions. Most experimentation in physics can be done satisfactorily on upper floors. In fact, some laboratories such as those at the University of Liverpool conduct research in tower-like buildings (Chapter 4, Figure 7). Physical apparatus does not need to be on the ground floor to be isolated satisfactorily from vibration. Furthermore, many chemical fumes are heavier than air, and little advantage is gained by discharging them at the top of the building. A more significant factor in determining the location of the chemistry department may be a knowledge of prevailing winds. The three departments—physics, chemistry, and pharmacy—that are housed in Malott Hall at the University of Kansas (Chapter 4, Figure 23) are distributed vertically rather than horizontally. The wing occupied by the physics department is so located that prevailing winds prevent disagreeable odors and corrosive fumes originating in other areas of the building from reaching the department.

Floor Loading

The floors in any building must be designed to take the loads they may be called upon to carry. In a physics building, these loads include such items as machine tools, stock bins, steel magnets and lead shielding. Since heavy duty floors can be constructed by pouring concrete directly on earth more economically than by beam and slab construction, heavy loads are usually assigned to on-grade locations.

The recommended design loading for most floor areas in a physics building is 100 pounds per square foot. We have seen new physics buildings with floor loadings from 50 up to 150 pounds per square foot. For certain areas such as offices 50 pounds per square foot is adequate. It is even adequate for other areas if special devices, such as timbers or I-beams, are placed under heavy pieces of equipment to spread the load over an acceptable area. On the other hand, to design for a load of 150 pounds per square foot throughout provides greater flexibility, but at considerably increased cost. Offices and other areas in the building will very likely never require such a loading. Furthermore, since concentrated loads can be spread when necessary, 100 pounds per square foot is recommended for all areas of the building except those where lower or higher loads can definitely be anticipated.

Acoustical Design

The architectural design of a building should provide good acoustical characteristics; to accomplish this the problems of acoustical design must be considered along with other factors in initial planning, and not left to be solved after the building is completed. Good acoustical design will influence such things as the selection of room shape, particularly for the lecture room, and the selection of building materials and finishes, and thus has definite structural implications. The fact that acoustics is a subject studied in physics makes it doubly ironic whenever a physics building ignores basic acoustical principles.

The acoustical problems of a physics building concern first good hearing conditions within rooms and second the maintenance of privacy and freedom from annoying "cross talk" between rooms. Such "cross talk" may not only be caused by the spoken voice, but also by the "tick" of chalk on the wall in the adjacent room. The acoustical problems of the lecture room are discussed in Chapter 5, and those relating to other areas of the building in appropriate chapters. We will discuss more general problems here.

A mistake in acoustical design occurs where suspended ceilings provide an open space for sound to travel between rooms. Air ducts without baffles and adequate insulation are other offenders. Where a stubbed wall extends only to a suspended ceiling, the space above the wall should be filled in to block sounds. This can be done by continuing with either the same construction as the stubbed wall itself or with less expensive construction. A less satisfactory solution is to blanket the underside of the structural ceiling with acoustically absorbing material. An expensive solution is to install much more massive, and thus more sound proof, hung ceilings in the first place.

The transmission of sound between rooms is also affected by the construction of the dividing walls. Concrete blocks are more widely used than other materials for such walls. Laboratory test data indicate that a typical 8-inch thick concrete block wall of standard density concrete and open cells has an average sound transmission loss of approximately 50 decibels; a 6-inch pumice or expanded shale block has a loss of approximately 35 decibels (average sound transmission loss over the range 100 to 3200 cycles). Both ratings are for painted walls with pores therefore sealed. It should be pointed out that laboratory measurements are made with test walls which are sealed at all edges and free of openings. Where good seals are obtained in construction, painted or plastered concrete block partitions serve quite satisfactorily for most areas of a physics building. The problem in practice is to obtain a sufficiently good seal. Cracks and pipe and duct openings, common offenders, should be properly filled.

Desirable as it may be to minimize the amount of noise which may interfere with one's work, it is not desirable to have a room too quiet. The smallest sounds will then be distracting, and conversation in adjacent rooms becomes intelligible. A certain amount of air duct noise or other low level nondescript noise is therefore desirable to promote privacy and to diminish the amount of distraction from unwanted sounds.[3, 4]

The increasing demand for higher space utilization is resulting in a search for sound resistant movable room dividers. Most currently available room dividers, whether accordion pleated or hinged doors, or variations of these, are only adequate as visual space dividers and nearly useless as sound barriers. Some are better than others through increased density and improved edge seals. All the better folding partitions are expensive; however, if their use leads to increased space utilization their cost can be soon amortized. The sound insulating quality of a wall increases with its mass and decreases with its stiffness. A promising current development is working towards limp walls of suspended dense materials—lead strands interwoven with standard textile materials, for example.[5] Equal attention is being directed toward improved seals at the edges using pneumatic or mechanical closures. All this is promising, but anyone considering the installation of such dividers should investigate their performance in actual buildings as well as the results of laboratory tests. Two lecture rooms shown in this book feature folding partitions —the Drexel Lecture Room (Chapter 5, Figure 31), which can be divided longitudinally, and the IBM Research Center Auditorium (Chapter 4, Figure 27), which can be divided transversely. The IBM treatment is noteworthy in that two distinct closures are used, thereby providing two independent walls with a space between them.

Suspended acoustical ceilings are finding wide acceptance in offices and public buildings and, when light fixtures and ventilation outlets are mounted in them, they provide a

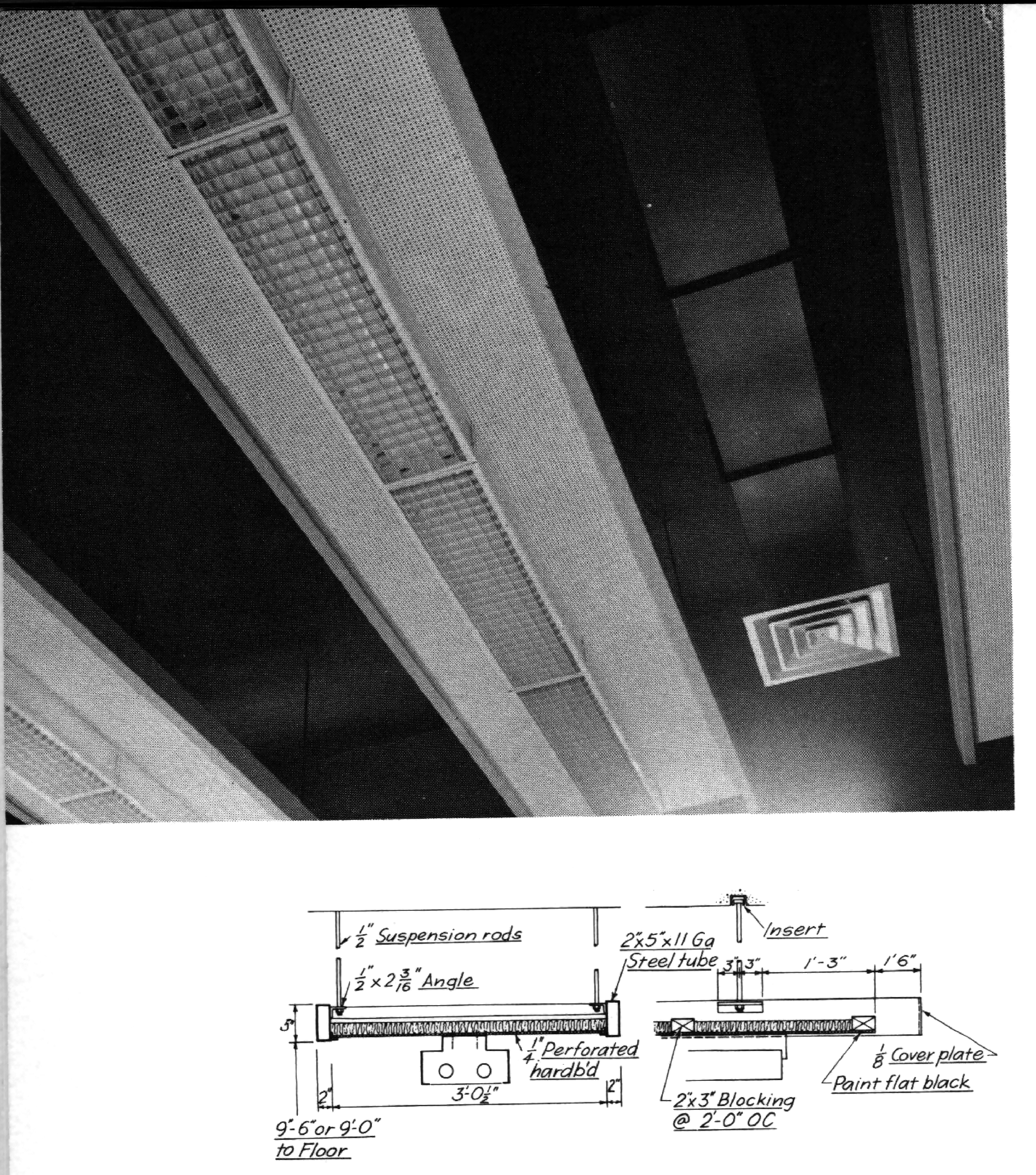


Figure 3. Suspended acoustical and light panels in laboratories in the new addition to the Physics Building at the University of Texas. Fehr and Granger, Architects, Austin, Texas.

coordinated system for heating, ventilating, air conditioning, and lighting as well as an acoustical treatment of the room. In physics buildings, suspended ceilings appear best suited to classrooms, hallways, and offices. Laboratories require occasional changes to the overhead services, and hung ceilings in practice are not as convenient to work above as would first appear. They are not substantial enough to support a workman and moreover, the space is usually cramped for work. As a result, metal T-bars and other supporting grids become damaged, and the acoustical tiles also become damaged and soiled.

An interesting solution which provides acoustical treatment of the laboratory ceiling and at the same time allows access to services near the ceiling has been used in the addition to the Physics Building at the University of Texas. As shown in Figure 3, the fluorescent light fixtures in the laboratory are integrated with acoustical panels. The top of each panel, as well as the bottom, is covered with high quality sound absorbing material, thereby increasing the effective area for the absorption of sound. The wide gaps between the suspended acoustical lighting panels provide ready access to the overhead services without the need to remove tile as is required in continuous suspended ceilings. By painting the suspended panels light in color and by using dark paint on the structural ceiling and equipment above, one normally does not observe the ducts, conduits, and pipes near the ceiling.[6]

Noise due to shop machines, ventilating and air conditioning machinery and all other types of heavy equipment in a building should be reduced to a minimum at its source. This requires careful dynamic balancing and shock mounting of all major machinery. The level of air borne machinery noise can be reduced by suspended absorbing units where ceilings are complex or where utilities and service access precludes more standard treatment. Various forms of suspended absorbers, such as glass fiber tetrahedrons and edge suspended panels, have proven quite effective in industrial shops, and their use is beginning to be seen in physics buildings.

Illumination

Fluorescent lamps are widely used for lighting physics buildings largely because of their much higher efficiency than incandescent lamps. The down lights and spot lights in lecture rooms are usually incandescent lamps, and incandescent lamps are sometimes installed elsewhere, frequently in corridors, for aesthetic reasons. The problem of radio frequency interference from fluorescent lamps is not serious and is discussed in Chapter 8.

The illumination levels required in the various areas of a physics building depend principally on the difficulty of the tasks to be done. The levels given in subsequent chapters are levels which are required in "average" rooms. Higher or lower levels may be required, depending on how well other factors are taken into consideration in designing the layout of working areas and the lighting that is installed.

A recent article by William M. C. Lam discusses the several factors which, in addition to illumination level, affect seeing.[7] Among other things, Lam gives a summary of some of the pertinent results of experiments made by H. R. Blackwell in which he studied how the illumination required for persons to see certain objects (that is, to identify detail in objects with average speed and accuracy) is affected by such factors as contrast in detail and the average reflectance of the object being viewed.[8] For example, for equal visibility, a dark object with only 8% reflectance required ten times the illumination of an object with similar detail which had a reflectance of 80%. Also, good typed copy with a reflectance of 62% could be read with an illumination of only one foot-candle, whereas copy which had been typed with a very poor ribbon required an illumination of over 3000 foot-candles to be read with the same speed and accuracy. The competing brightness of other surfaces that lie in the field of view also affects visibility. In general, adjacent surfaces should have about the same brightness as that of the object being viewed. The direction of the incident light is also important in that glare from specularly reflected light reduces contrast in detail and therefore requires a higher illumination for the same visibility. Lam also points out the psychological advantages derived from careful lighting designed for "visual comfort." Light fixtures should be of such a type and so located that they do not call attention to themselves, but rather serve to produce the required lighting—both the desired environment and the special illumination that may be required.

Good illumination, therefore, does not necessarily mean a high level of illumination, and cannot be measured in foot-candles alone. Light sources should have low surface brightness, and therefore large diameter fluorescent lamps are to be preferred over the smaller lamps if they are not shielded. If rooms are low, light fixtures should throw some light onto the ceiling to decrease the contrast between the lamp and its background. Light cast on ceilings, walls and floors can add interest by a variation in pattern and in color, or by highlighting certain architectural features. Furthermore, those light fixtures which are designed to produce the direct illumination of objects to be viewed should be placed so that glare is not a disturbing factor. The lighting requirements for each room must be designed individually.

Mechanical and Electrical Design as Related to Structural Design

The need for flexibility should be emphasized in any discussion of mechanical and electrical services for a physics building. Services should be installed so that rooms can change their function with a minimum of expensive alteration. Frequently, changes in mechanical and electrical facilities are required within existing rooms. It should be possible to meet unforeseen requirements promptly and economically.

Research laboratories demand extensive electrical and mechanical equipment. This equipment is needed both as experimental equipment and as building equipment to support experiments. Magnets and electronic power supplies, for example, not only require heavy electric currents but produce excessive heat which must be removed. Heat removal, in turn, requires cooling water and pumps, refrigerant and compressors and/or cooling air and fans. Air conditioning to provide temperature and humidity control is essential for much of research. At the same time, the comfortable and more efficient working conditions made possible for personnel by air conditioning are becoming accepted as a need rather than a luxury. Air conditioning

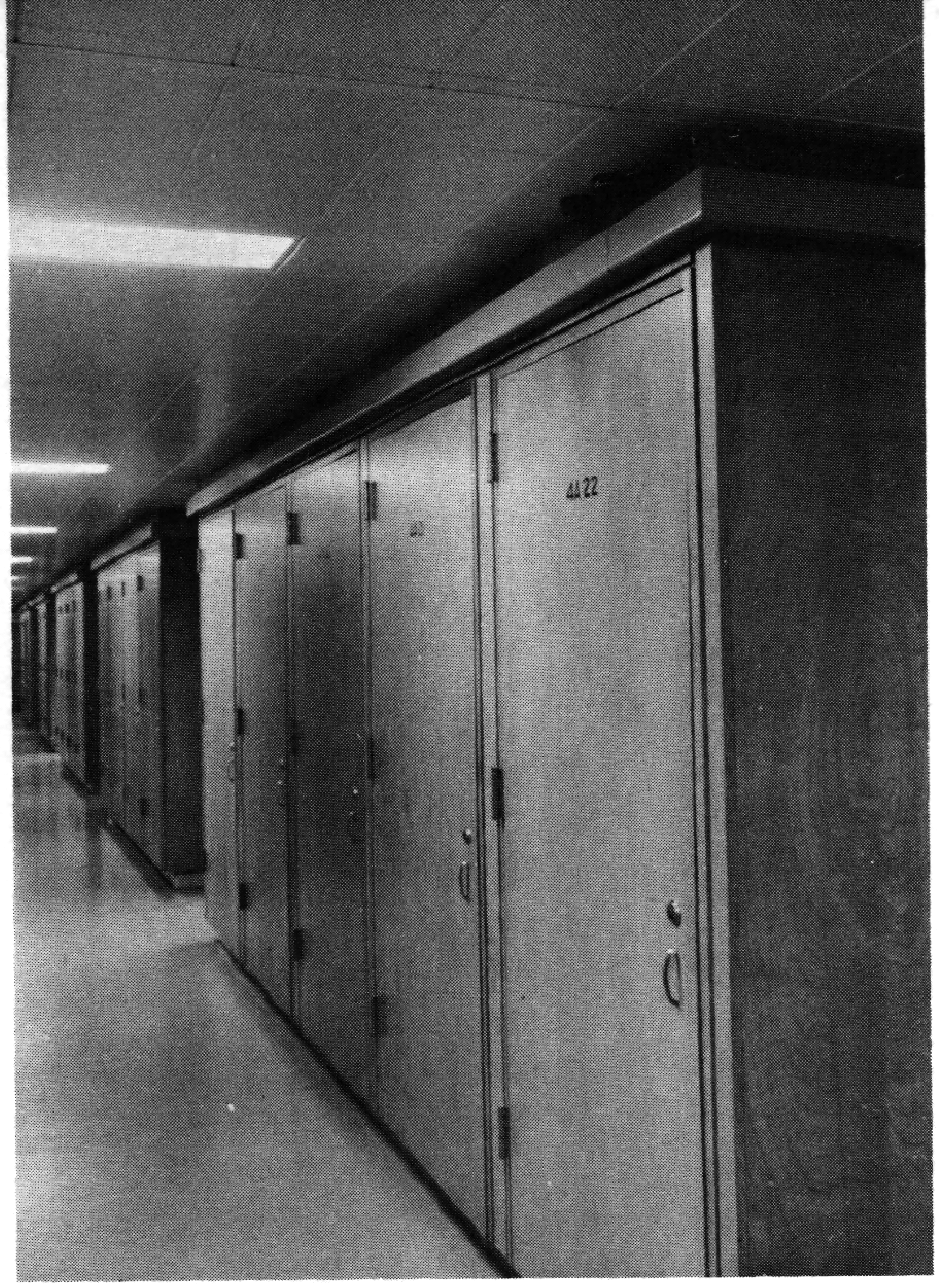


Figure 4. Cases are installed in the corridors in the new Physics Building at the University of Illinois (See Chapter 4, Figure 6). The channel running along the corridor near the ceiling contains telephone and signal lines and is open at the top so that additional cables can be laid to interconnect rooms.

will be discussed in more detail later, along with heating and ventilating.

Mechanical and electrical services are distributed in a building by means of a variety of sizes of ducts, pipes, conduits, bus bars and cables, and they usually share common rights-of-way. Vertical shafts, horizontal and vertical furred spaces, suspended runs underneath floor and ceiling slabs, and below-grade trenches and service tunnels are routes that are standard for many types of buildings. The distribution required in a physics building differs from others principally in the kinds and quantities of these services and in their above-average need for adaptability and change.

The vertical distribution of services in a multi-story building is usually provided through service shafts at every column or at every other column from horizontal feeder lines in the basement. Access is available at each floor, with valves and switches, junction boxes and tees to which horizontal lines can be connected. Service shafts at corridor walls provide easy access for repairs, changes and shut-offs in the event of emergencies. Service shafts at outside walls allow continuous horizontal distribution along the wall at each floor, and offer more flexibility in interior space arrangement, especially if large open areas are desired. However, this method is less frequently employed.

All enclosed rights-of-way should have covers which can easily be removed without damaging them. Furthermore, the space allotted should be large enough so that additional services can be installed and so that workmen can make changes efficiently and with a minimum of discomfort.

Cables can be run from room to room in the new Physics Building at the University of Illinois by simply laying the cables in the channels which run around the corridor walls near the ceiling, as shown in Figure 4. The channel houses telephone and signal lines, and is open at the top to take additional cables as needed.

Office buildings make wide use of in-floor duct systems (so-called "Q-floor" systems), with repetitive outlets at frequent intervals, for the distribution of electric power and for communication systems. Since physics buildings have a much larger and more unpredictable localized need for power, such systems would have to be over-designed to provide the required flexibility for physics.

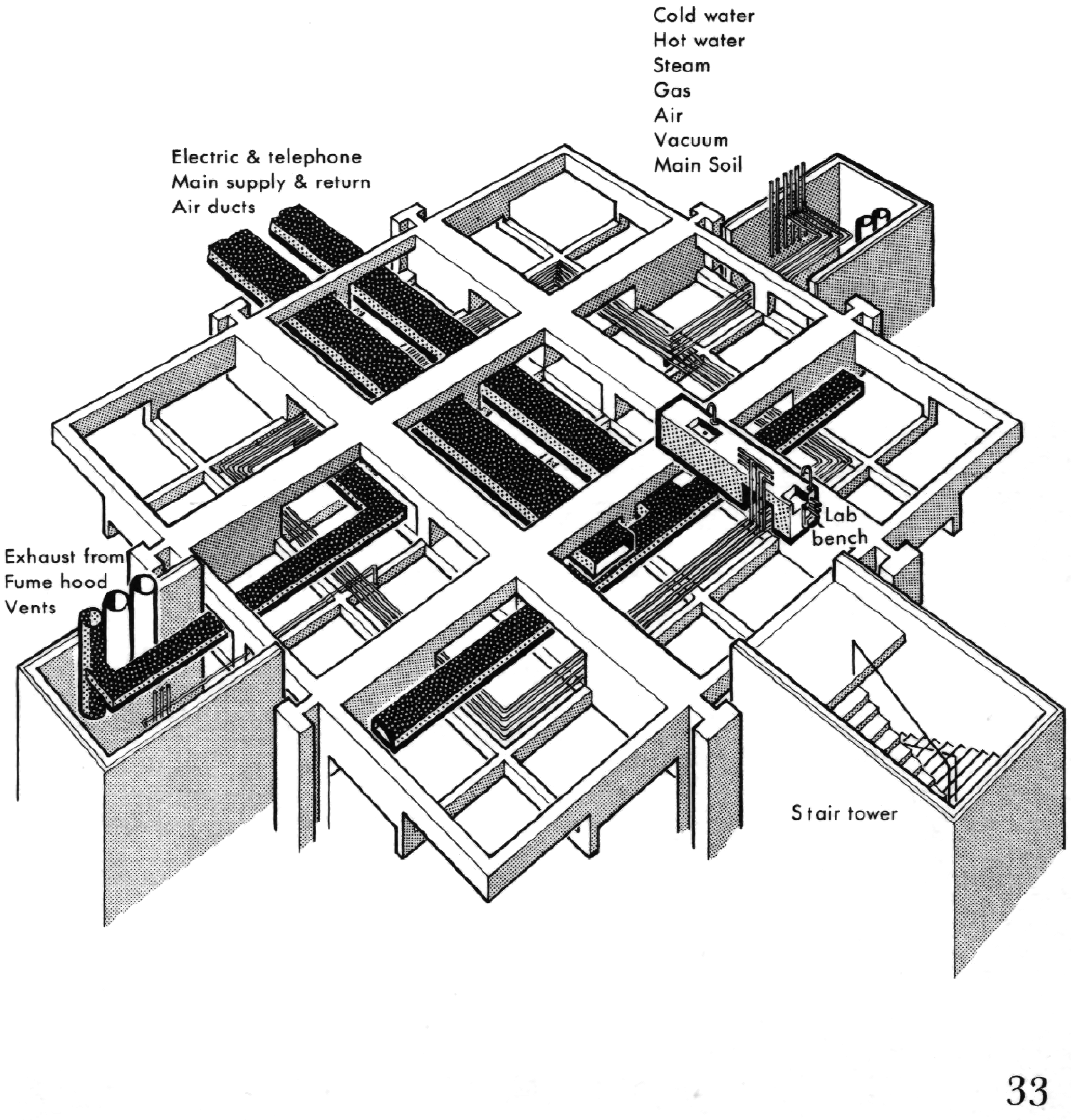
The Structural Module

The even column spacing of buildings finds expression today in the external emphasis on the building "bay," the most recognized module of construction. This in itself is not new, but it is gaining in emphasis and has overtones of a "fashion" approach to design. As viewed from outside, the exterior walls of many physics buildings make a special feature of the column spacing module. Often the window mullion spacings are regular, evenly spaced geometrical subdivisions of these building bays, and further express a repetition of the building module. A danger to be avoided is that of allowing the building module to determine internal room layout by not permitting any partition to vary from it. Useful areas can be arbitrarily reduced and others unnecessarily increased when walls are forced to fall at module divisions rather than where more functional space requirements would place them. This sometimes results in cramped clearances in restricted spaces. Excessive use of glass often follows the same desire to express the module in exterior appearance. The use of continuous windows has in fact become a current badge for identifying some modular buildings. Continuous windows eliminate useful wall areas and have other disadvantages which will be discussed later. These limitations, as well as the advantages of strictly modular planning, should be recognized when deciding to use strongly modular schemes. Forcing of a plan to conform to a preconceived module while giving an apparent cleanness of design and a stylish modern appearance can actually impair the very flexibility it would serve. This is not a reaction against the laudable current trend towards functional architecture. Rather, it is to stress the point that structure should interfere as little as possible with the principal function of the building.

Structures

The details of the structural framing of the physics building are generally designed by a structural engineer. The architect's influence is strongest in the selection of the basic structural framing schemes, such as whether the building shall have bearing walls or a skeleton frame, whether the frame shall be steel or concrete, and whether concrete slabs shall be smooth or beamed. The structural engineer may be best informed on the costs and merits of the various structural schemes, but the architect must have the final decision because the structural scheme has more to do with the functioning of the building than its immediate function of making the building stand up. The decision, for example, of how and where to run pipes, conduits, and ducts for the mechanical and electrical services is tied up in many ways with structural design decisions. If it is decided that many pipes, conduits and ducts are to run horizontally below floors, this decision will generally rule against selecting a structural system with deep beams and girders. An exception is illustrated in the framing of the new Alfred Newton Richards Memorial Medical Research Center at the University of Pennsylvania (Figure 5). Here the concrete girders are pierced by numerous rectangular openings to allow weaving in the mechanical and electrical services. Actually some of the girders, by virtue of so many openings, become Vierendeel trusses. In more typical

Figure 5. Diagrammatic perspective of structure and services showing unique method of distribution of services within truss space. Alfred Newton Richards Memorial Medical Research Building, University of Pennsylvania. Louis Kahn, Architect, Philadelphia.



buildings, the requirement of numerous horizontal pipes, conduits and ducts suggests the desirability of a smooth ceiling structure. Where deep girders are used, major lines of services are normally routed parallel with the girders. Long span beams and girders permit more flexibility of room arrangement both originally and in the case of alterations. This advantage, of course, must be weighed against the increased cost of long spans and the fact that they present irregular profiles for partitions.

The foundation, with its attendant soil test borings, influences the design for any large building. In the case of the new Engineering Building which houses physics at Colorado State University, the soil bearing conditions required the use of concrete caissons. Since caissons are expensive, a structural system was adopted which required only two columns; hence, only two caissons per bay. The floor plans of this structure are shown in Chapter 4, Figure 18. By balancing the positive and negative moments in the spacing of the columns and by using cantilevers, the architect has given the structural system a dominance not usually given to structure in college buildings. The architect has weighed the inconvenience which sometimes results when columns are located away from corridor and outside walls (sometimes in the middle of a room) against the savings in structure, and states he is convinced of a net gain through use of such a system. This is an interesting example and the only one of its kind we have seen among some 50 college science buildings studied. The architect maintains that the two-column system has such promise that he will continue to use the system on other college buildings. He states, "the two-column system also provides a longitudinal girder, a natural for the hung ceiling and utilities access . . . the relatively thin plate slab is easy to dig through for utilities for lab tables. . . . Additional plus factors lie in the ability to erect yards and yards of 'weather skin' (curtain wall) without fitting to columns, slabs or other structural members."

No obvious structural system emerges from our study as the one best adapted for all physics buildings. We have seen buildings in stone, brick, steel and concrete. Current building practice does suggest that reinforced concrete, including precast and prestressed concrete, is gaining increasing acceptance. Curtain wall exterior construction is now so common as to be the standard exterior wall treatment. The Varian Associates' Radiation Building (Figure 6) and Swarthmore College's new Science Building (Chapter 4, Figure 25) both use concrete for framing as well as exterior curtain wall panels. The traditional tendency to require that new campus buildings "match" older ones still inhibits building structure as well as appear-

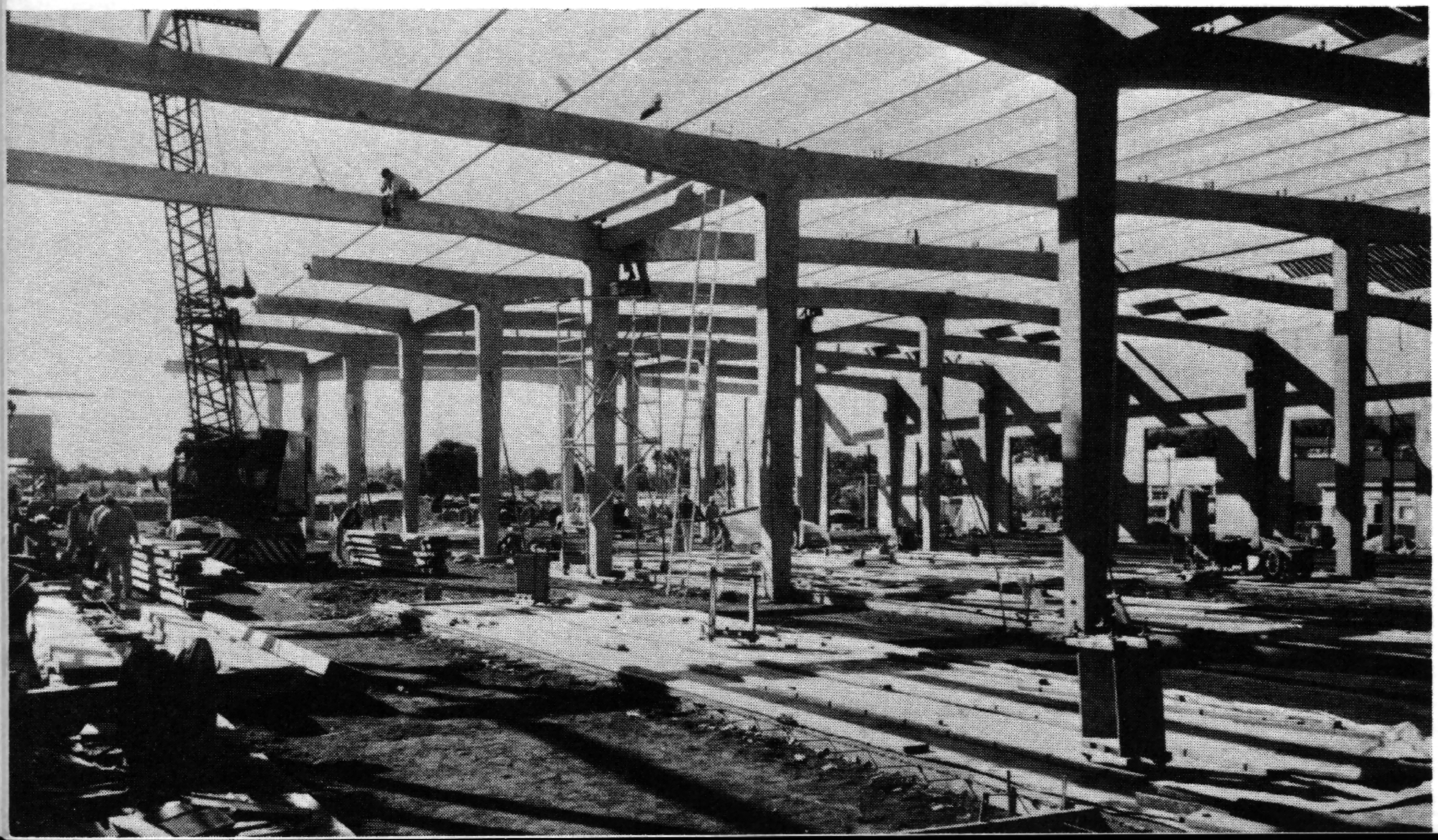


Figure 6. Radiation Building, Varian Associates, Palo Alto, California, shown under construction. Note precast concrete bents. An economical structural system permits the foundations for the columns to carry also the precast wall panels which extend below grade. Michael Gallis, Architect, San Francisco.

ance on many campuses. But there is increasing pressure, including that of cost, to break with tradition. The science building and the physics building are often among the first to provide newer and more straight-forward methods of construction.

Following a discussion of the mechanical and electrical requirements of a physics building, we will give some examples to illustrate how the distribution of services can be integrated with building structure.

MECHANICAL AND ELECTRICAL SERVICES

Laboratory Services Required in a Physics Building

The mechanical services found useful for distribution in physics laboratories include cold water, hot water, distilled water, drains, gas, compressed air, and vacuum. Electric service requirements include 120 volts single-phase ac voltage, 3-phase ac usually at 208 volts, occasionally higher ac voltages, direct current at various voltages, coaxial cable, and a separate ground in addition to the ac neutral ground. The extent to which each of these services is required in the various areas of the building is discussed in subsequent chapters.

Of these services, the only ones which are quite universally distributed building-wide are cold water, drains, gas, compressed air, and 120 volt single-phase ac. Hot water is occasionally distributed; distilled water and vacuum, quite rarely. Commercial electric power is quite widely installed as 4-wire 120/208 volts 3-phase ac, and hence both single-phase and 3-phase power at each of two voltages are then available. A central dc motor generator system and free lines from a central distribution board are installed in most but not all physics buildings. Coaxial cable is occasionally installed between certain rooms (sometimes in connection with a central distribution system) to transmit pulses and high frequency signals, such as for television. Certain of these services will be discussed individually.

Notes on Mechanical Services

WATER. Water is usually distributed in galvanized iron piping, though copper tubing is becoming more common. Where hot water is provided, pipes should be insulated and preferably looped for continuous circulation to reduce delay and waste in obtaining hot water at the tap. Where hose connections are not required, standard rather than special laboratory valves can be used, as for example at wash-up sinks. Here standard kitchen mixing valves serve well with saving in cost over laboratory valves. A quick-connect type of fitting which permits convenient connection to pipes and faucets is the Snap-Tite coupler. (Manufactured by Snap-Tite, Inc., Union City 9, Pennsylvania.)

Distilled or treated water can, of course, be distributed building-wide, using plastic, tin, aluminum, lead, or glass systems. However, the initial cost of extensive piping and valves together with maintenance costs—including waste through unnecessary use—suggest the restriction of distribution to those areas where the water is regularly required. For most work in physics it is quite satisfactory simply to carry in containers of distilled or treated water from a central source as required.

GASES. Manufactured or natural gas for torches and general laboratory use is usually distributed in black iron piping, although copper is also used. Some local codes have safety provisions which require that gas pipes be exposed to the maximum degree possible. Although gas is usually distributed building-wide, the use of portable gas cylinders has enabled some laboratories to limit the distribution and even eliminate it altogether. Gas cylinders of various sizes are available commercially, including small hand-held cylinders, and with certain gases hotter flames can be obtained than with conventional manufactured or natural gas.

Other gases such as oxygen, helium, and hydrogen are sometimes distributed in certain areas of a physics building, but both the costs and the hazards involved strongly point to restricting such distribution. Gases are best handled from cylinders at the place of use, or locally piped from only a short distance away. Gas cylinders should be held upright with safety chains to keep them from falling over and possibly exploding and to save their valves and regulators from damage. A definite area should be reserved for storing tanks. It should be ventilated and conveniently accessible for truck delivery. Tanks are stored on the loading platform at the rear of the new Physics Building at the University of Illinois, as shown in Chapter 9, Figure 16.

A single gas cut-off valve should be supplied each laboratory room, and left turned off except when needed. The Bronx High School of Science (Chapter 12, Figure 3) has such a valve conveniently located at the door to each laboratory.

COMPRESSED AIR. The principal problem in connection with the distribution of compressed air is that of water vapor. The moisture content of the air can usually be diminished to a satisfactory level by passing intake air over various salts which absorb water vapor, or through refrigerating coils to freeze out water vapor, or by re-expansion to chill the air and condense out excess moisture. Piping and valves for compressed air offer no particular problem.

VACUUM. Rough vacuum is sometimes distributed in physics buildings, but its use does not warrant wide distribution. House vacuum systems cannot be relied upon for other than rough vacuum at best because of leaks which are hard to locate and valves which are carelessly left open. Satisfactory vacuum for research can only be obtained by individual vacuum pumps.

STEAM. Steam is seldom distributed as a laboratory service, though it is occasionally given a limited distribution where it is used for heating. Where steam is available along with cold water, hot water can be obtained with suitable mixing manifolds or heat exchangers.

Notes on Electric Service

ELECTRICAL LOAD AND ENTRANCE DETAILS. Electric service normally enters the physics building area underground, and two or more entrance feeders are often provided to assure uninterrupted service. Power is supplied at a high voltage determined by local utility practice, and is stepped down to the usual 120/208 volts 3-phase, for local 4-wire distribution.

In estimating the electrical load requirements for a physics building, designers experience more unknowns than for most other buildings. To allow for needs that cannot be predicted, oversize transformers should be installed initially, and transformer vaults should be large enough to take additional or larger transformers when the need arises. Doors in the roof of an underground vault adjacent to the building simplify making such future changes. Although smaller and more efficient transformers are continually being developed, one cannot rely on this development to solve future space problems. Adequate reserve space should also be provided throughout service rights-of-way, and spare conduit can be installed in some areas.

Table III gives the power requirements of a typical college physics building, presented to show a method of breakdown. It should

Table III. Power Requirements for a Typical College Physics Building

	volt-amperes per sq. ft.
Light	3.5
Service including air conditioning	6.0
Laboratory power	3.5
TOTAL	13.0

be recognized that each of the figures given can vary widely. For example, a variation of from 35 to 100 foot-candles in level of illumination can cause the power required for fluorescent lighting to vary from about 2 to 6 volt-amperes per square foot. Air conditioning requirements will vary with geographic location, building orientation, window area, and extent of internal heat sources such as encountered in research equipment, and thus can require anything from 1 to 6, and even more, volt-amperes per square foot. Normal building service requirements vary from 0.5 to 3 volt-amperes per square foot. The most uncertain requirement is that of research. One cannot even suggest a range without knowing the type and probable extent of future research activity.

Power is supplied in the new Physics Building at the University of Illinois (Chapter 4, Figure 6) at a rate of 18 watts per square foot. Standard 4-wire 3-phase 120/208 volt service is provided. Power is distributed along one end of each laboratory by exposed overhead bus-duct and line drop at average load is small—between 1 and 2%. Installed equipment in any one laboratory room may require several times 18 watts per square foot, but the anticipated simultaneous load in all laboratories is expected to be substantially smaller.

To predict future building loads requires experience plus intelligent guessing. Electric companies such as General Electric and Westinghouse have published data based on past experience for a number of industrial applications which have relevance to research laboratories. The national and local electrical codes specify certain minimum requirements. The integration of such code requirements with other established needs provides an intelligent approach to the design of the electrical facilities for a physics building.

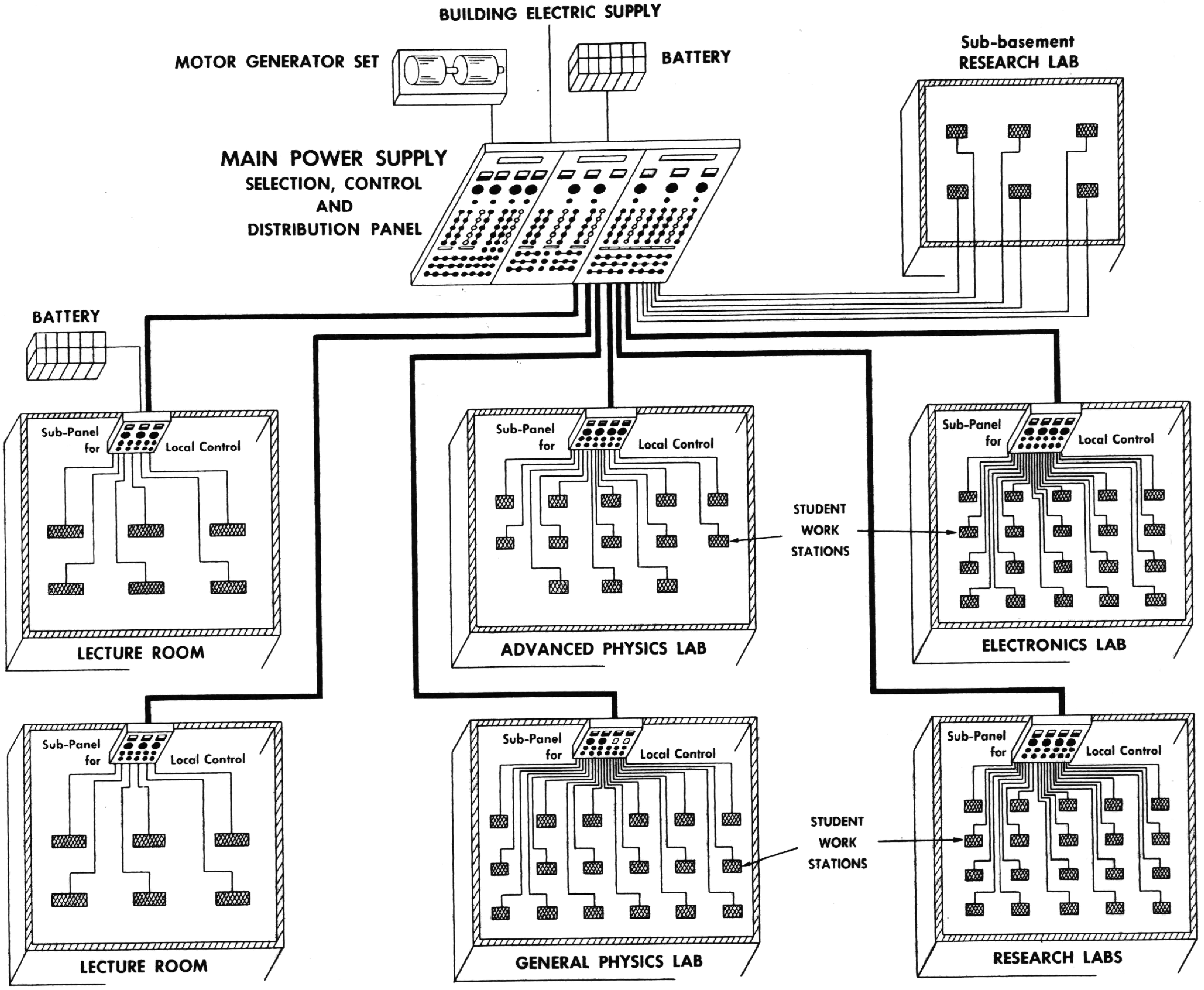
AC Distribution. Either 120 volts or 208 volts, single-phase or 3-phase, is available from the commonly distributed 120/208 volt 3-phase Y-connected 4-wire ac system.

There is wide agreement among physicists as to the advantage of a generous distribution of standard 120-volt 60-cycle ac service. The number of tools, pieces of electronic equipment, and experimental gear of all descriptions which can be plugged into the common 120 volt ac convenience outlet continues to grow. These outlets should be of the grounded type which permits the use of both 2-prong standard plugs and similar plugs which are provided with an additional third grounded terminal.

Rigid conduit is widely used for the distribution of both ac and dc power within the physics building. Increasing use, however, is being made of bus duct as well as metal wire raceways and open trays. These latter systems provide greater flexibility than conduit unless the conduit is interrupted by frequent junction boxes. Raceway and bus duct systems can be coordinated with switches, multiple outlets and circuit breakers. Surface metal raceways have made considerable advancements in the past few years both from the standpoint of design and application; it is significant that codes now allow surface raceways to carry a larger number of conductors than were formerly permitted.

DC Distribution. The direct current required in a physics building can either be supplied by local units—batteries, rectifiers or generators which are more or less portable —or by some sort of a central system, designed either for the building as a whole or for a restricted area such as the elementary laboratories.

Central DC Distribution Systems. A central distribution system enables one to interconnect rooms at a central distribution board and to make use of a common central dc supply—batteries, generators or rectifiers —at any place in the building. Central systems are custom built to suit the needs of the individual laboratory, either by companies which specialize in their design and installation or by a local contractor. (Hampden Engineering Corporation, East Long


BUILDING ELECTRIC SUPPLY
MOTOR GENERATOR SET
BATTERY
Sub-basement
RESEARCH LAB
MAIN POWER SUPPLY
SELECTION, CONTROL
AND
DISTRIBUTION PANEL
BATTERY
Sub-Panel for Local Control
LECTURE ROOM
Sub-Panel for Local Control
ADVANCED PHYSICS LAB
STUDENT WORK STATIONS
Sub-Panel for Local Control
ELECTRONICS LAB
Sub-Panel for Local Control
LECTURE ROOM
Sub-Panel for Local Control
GENERAL PHYSICS LAB
STUDENT WORK STATIONS
Sub-Panel for Local Control
RESEARCH LABS

POWER AND VOLTAGES AVAILABLE IN LABORATORIES, POMONA COLLEGE

LECTURE ROOMS

TYPE	VOLTAGE
D-C	0-125
D-C	0-36
D-C	0-45
A-C	0-120-1 ∅
A-C	120
A-C	208-3 ∅

LABORATORIES

TYPE	VOLTAGE
D-C	0-125
D-C	0-36
D-C	0-45
A-C	0-120-1 ∅
A-C	120

IN ADDITION ALL ROOMS ARE INTERCONNECTED THROUGH CO-AXIAL CABLE

PHYSICS BUILDING, POMONA COLLEGE, CLAREMONT, CALIFORNIA

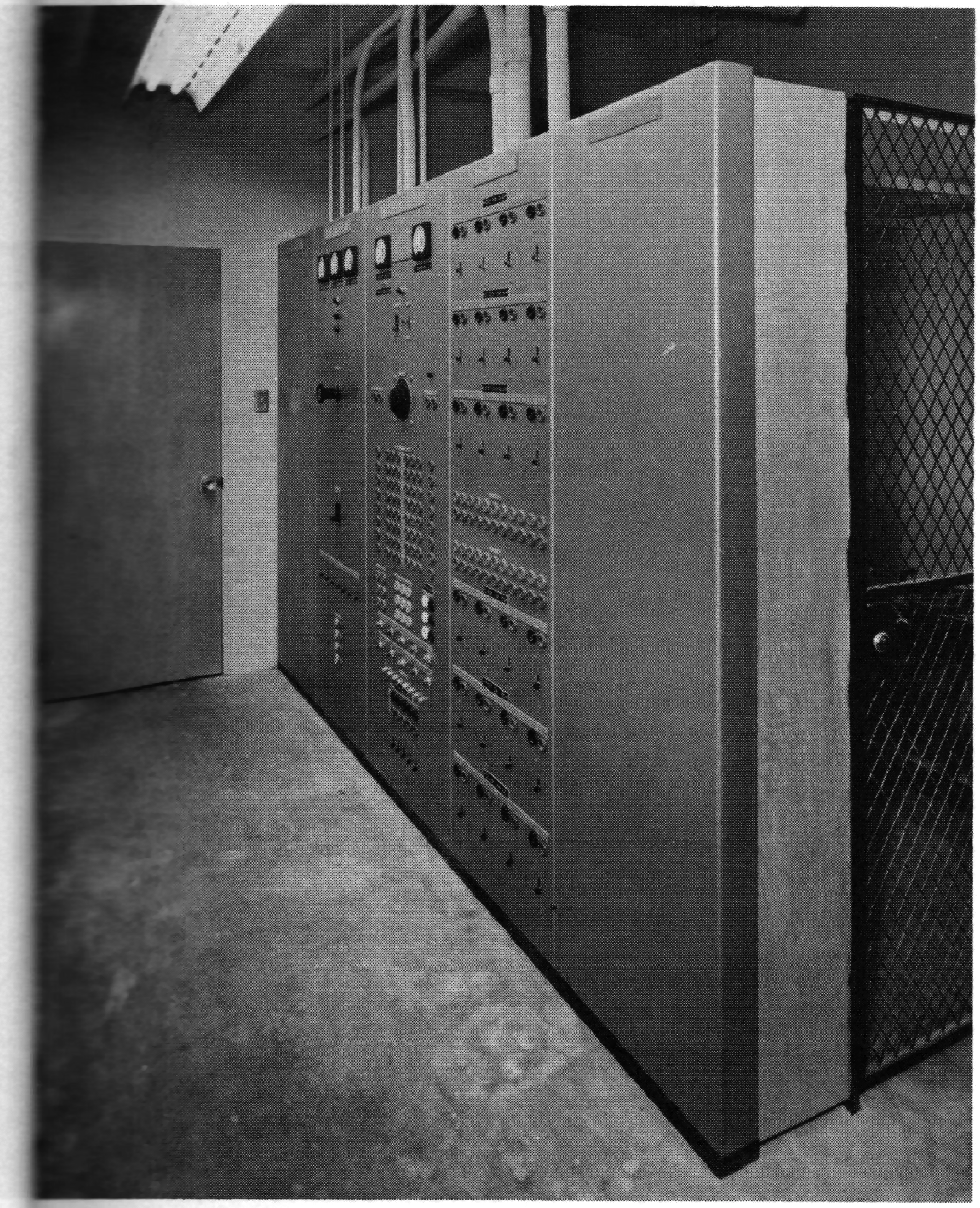


Figure 7. Central electric power distribution panel at Pomona College (See Chapter 4, Figure 11). Schematic of system is shown on facing page.

Meadow, Massachusetts, and Standard Electric Time Company, Springfield, Massachusetts, are companies that specialize in this type of work.)

Great flexibility can be provided by such systems and certain economies as well (by dispensing with some of the separate local sources of dc), *providing the flexibility is not pushed too far.* Frequently, much more elaborate systems are installed than can be justified in terms of the likelihood of demand for the services provided.

Central distribution systems are being installed in many new physics buildings. However, there are some notable exceptions. The recent availability of rectifiers which could handle large currents at low power loss has convinced some departments that their needs could be met more economically by individual power supplies than by a central system. A central system was installed in essentially every new physics building a decade or so ago. New wings have recently been added to many of these buildings and in several instances their central system was not extended into the new wing. At a number of other institutions, the system has fallen into disuse and is not being replaced. To be sure, some of these older systems were not as versatile or as adequate as those currently available—either in design or in current carrying capacity.

The central power distribution system installed in the new Physics Building at Pomona College is an example of the versatility and convenience that can be provided by a well designed system. The schematic layout of this installation is shown in Figure 7, together with a photograph of the central distribution board. Controls for the 120 volt dc generator and four pairs of receptacles connected to the output of the generator are mounted on the left hand panel. A variable voltage transformer and controls for charging the bank of storage batteries, and receptacles from individual and groups of batteries, are mounted on the central panel. The right hand panel houses receptacles for four pairs of free lines which run to each of six areas in the building, appropriate circuit breakers, and four rows of receptacles for making multiple connections. Connections are made between panels by flexible cables terminated with suitable plugs. Terminals for coaxial lines to all points in the building and receptacles connected to the output of the variable transformer are also mounted on the central panel. The sub-panels in the six areas of the building provide for further distribution of the voltages, as suggested by the schematic diagram. The sub-panels in the main lecture room are shown in Chapter 5, Figure 28.

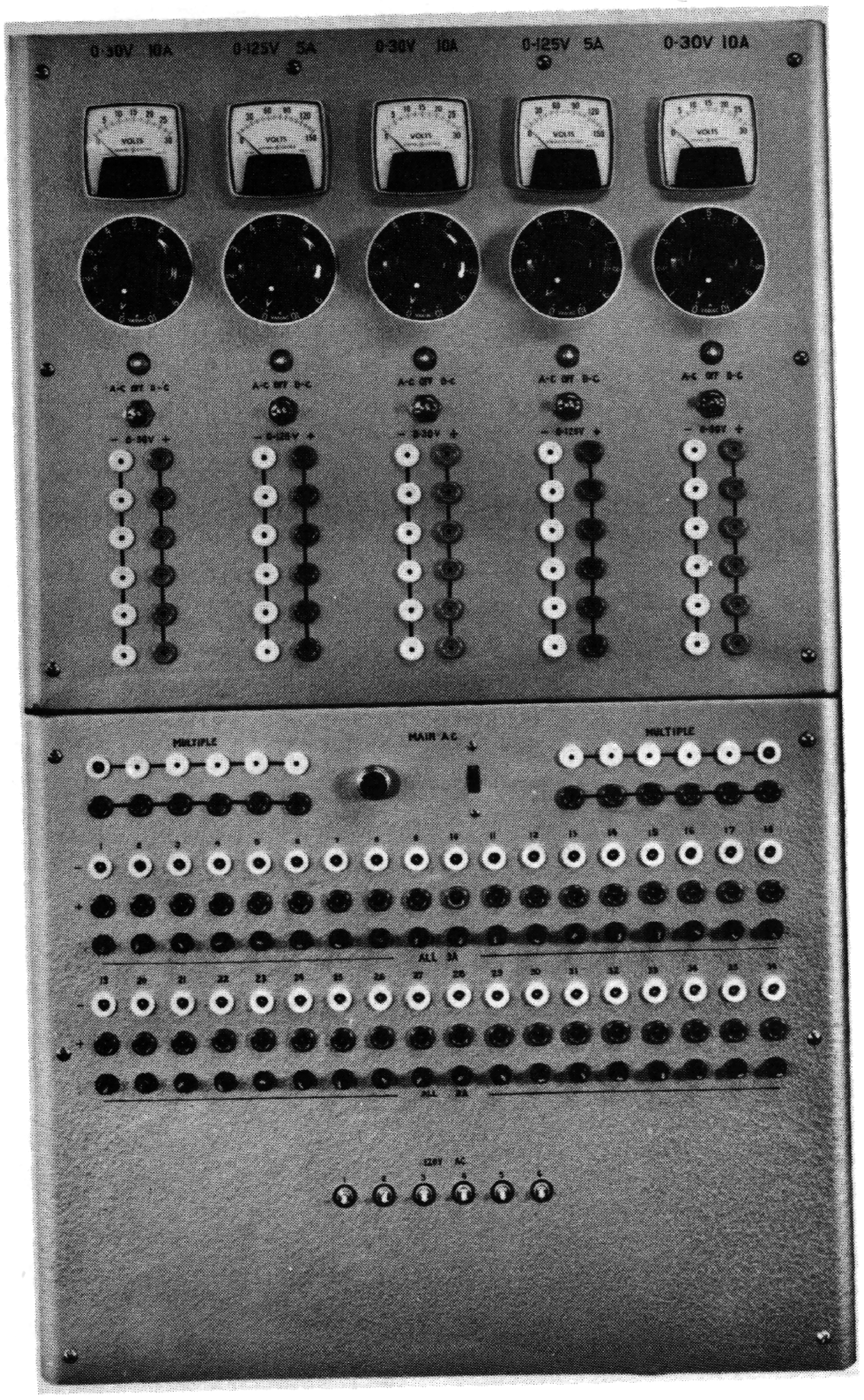


Figure 8. Electric distribution panel for a single laboratory.

Figure 8 is an example of a distribution system for a single laboratory. Five different variable transformers supply either ac or dc (by way of rectifiers) to receptacles which may in turn be connected by flexible cables to any one of 36 pairs of free lines. This would provide two separate circuits at each of 18 work stations. The individual rectifiers provide either 0-30 volts or 0-125 volts at either 5 or 10 amperes. Alternatively, such units are frequently constructed with but two rectifiers, in which case the rectifiers should have a higher current rating. Having a large number of rectifiers available means that there will be less interference between individual work stations, either from fuses blown or from variations in current demand which change the voltage drop in the line. Receptacles for multiple connections (four rows shown) make it possible to interconnect any pair of stations in the laboratory.

A still simpler distribution system is installed in a number of laboratories. For example, in each of the elementary laboratories in the new addition to the Physics Building at the University of Texas, a single 2-wire circuit connects the dc outlets at all 12 student stations to a panel on the instructor's desk where the desired dc voltage is supplied by a portable set of batteries or by a rectifier. As an emergency measure, power can be obtained from the central distribution system in the main building by way of a single pair of lines which connects all panels in the seven new laboratories together and to the central distribution panel. The central distribution system was not otherwise extended into the new wing even though, in addition to offices and the seven elementary laboratories, this wing also houses two lecture halls, advanced laboratories, and research laboratories. Reliance is placed on a "generous distribution" of 120 volt 60 cycle ac, together with local batteries and rectifiers for electric power.

Motor Generator Systems. One or more motor generators are quite common in physics buildings, with lines installed to distribute the voltage throughout the building. Even where free lines associated with a central system are available, separate lines are usually run to those areas of the building where the generator voltage is most frequently required.

Local Sources of Direct Current. Local sources of direct current that are under the immediate control of the user are a necessity for many experiments. Voltage fluctuations are produced when others are connected to the same source, and when fluctuations cannot be tolerated one must rely on local batteries or rectifiers. Furthermore, occasional heavy currents may be required in almost any laboratory. If lines were sized large enough for maximum possible loads, the costs would be prohibitive; moreover, one cannot anticipate where heavy loads will be required. For these reasons, a number of physics laboratories are now relying entirely on local batteries and rectifiers for direct current. For example, no central source of dc was installed in the new Physics Building at the University of Illinois (Chapter 4, Figure 6).

Heating, Ventilating, and Air Conditioning

More and more physics buildings are including year-round temperature and humidity control, not only for human comfort but also for reliable operation of a wide variety of modern physical instruments. Some institutions are as busy during the summer as during the academic year, with heavy summer session enrollments, summer institutes and conferences of many kinds, and augmented research programs; to attract students and retain faculty, an environment conducive to study and satisfactory research is necessary.

Temperature and humidity control is essential in many fields of experimental research, not only because the reliable functioning of much equipment depends on it, but also because the effects of normal ambient temperature variations may mask the effects sought in the experiment. Some experiments require precision temperature control in constant temperature rooms, especially designed for this purpose.

Electronic equipment, in particular, consumes so much power and dissipates so much heat, that air conditioning is required (1) to remove the heat generated; (2) to reduce the relative humidity to an acceptable value, so that leakage resistances remain high, short circuits are minimized, and the deterioration of electronic components is retarded; and (3) to maintain a relatively constant temperature, well below the rated maximum operating temperature of the equipment, so that the performance of the equipment will remain constant. Tropicalized equipment can meet relative humidity requirements but not the other two.

Many different systems of air conditioning are available, and which system will be best necessarily depends on individual circumstances. An air conditioning system should supply a physics building with clean, dust-free, dehumidified air, and it should circulate the air efficiently. Filtering and cleaning the air is essential, since airborne dust and dirt tend to settle on equipment and invariably affect its operation adversely; when forced air is used to remove the heat from compact electronic assemblies, for example, the dust which collects on them may bridge adjacent conductors and cause short circuits. The circulation of dust-laden air obviously increases the maintenance required in offices, laboratories, classrooms, and shops.

The air-conditioning system in a physics building should afford complete control of the environment in each individual area. An on-off switch and thermostatic control should be installed in each area, to regulate cooling and fix the temperature locally. The cooling requirements of spaces occupied by equipment consuming large amounts of power, and spaces devoted to continuous experiments, are so different from those of lecture halls, classrooms, or machine shops, that the installation of more than one system should be considered. Since working hours in a physics building are far less regular than in a typical office building, a central system turned on in the morning and off in the late afternoon is not acceptable. On the other hand, a central system in constant operation 24 hours a day and seven days a week is not likely to be economical. If the occupant of a particular area is to be able to turn the air conditioning on or off at will, and to adjust the cooling capacity in order to remove the heat generated and to maintain a relatively constant temperature, individual or unit air conditioners may be the most satisfactory answer for maximum flexibility in control.

Every effort should be made to minimize the amount of air that is either expensively heated or cooled and is then exhausted to the out-of-doors. Standard fume hoods which require in the neighborhood of 500 cubic feet of air per minute are the principal contributors to this loss. Small box-type hoods which require only one-tenth this amount of air are now available commercially and are quite satisfactory for many purposes. The number of hoods required by chemistry and biology departments, as well as the sizes required, should be carefully reviewed in planning a new science building. Separate fans for individual hoods will accommodate more readily to future changes than a single fan for the entire system.

One cannot balance the cost of air conditioning against its major advantages since these cannot be measured in dollars and cents. However, other savings are made possible and some of these can be estimated. For example, a building designed with interior rooms made possible by air conditioning—completely satisfactory for many functions for physics—results in less expensive perimeter wall for a given floor area since such structures can be more compact. Furthermore, an air-conditioned building can have less window area, with resulting savings when operating costs are also considered.

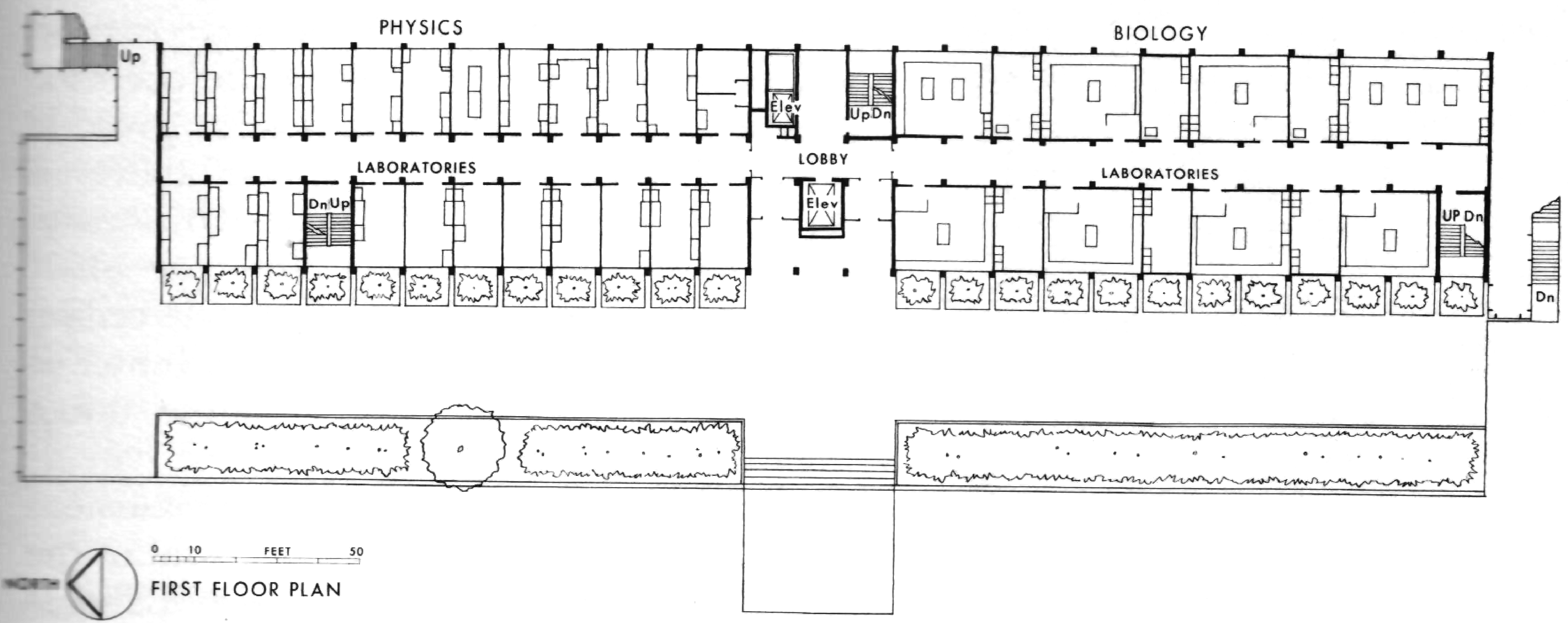
Some air-conditioning systems are noisy; but since acoustics has become more a science than an art, there is little excuse today for installing a noisy system. Lecture halls and classrooms are too often virtually useless while air is being forced through them. Fortunately, corrective measures are simple in principle; however, preventive measures are simpler still—both in principle and in execution. The proper installation of all ventilating and air conditioning equipment requires (1) proper dynamic balancing of all fans and rotating machinery; (2) vibration and shock mounting of all machinery; (3) ducts which are lined on the inside with sound absorbing material and treated on the outside with a vibration damping coating; and (4) inlet and outlet fixtures that are sized and streamlined to be quiet. Helpful information on air conditioning systems is presented in the *Heating, Ventilating and Air Conditioning Guide.*[9]

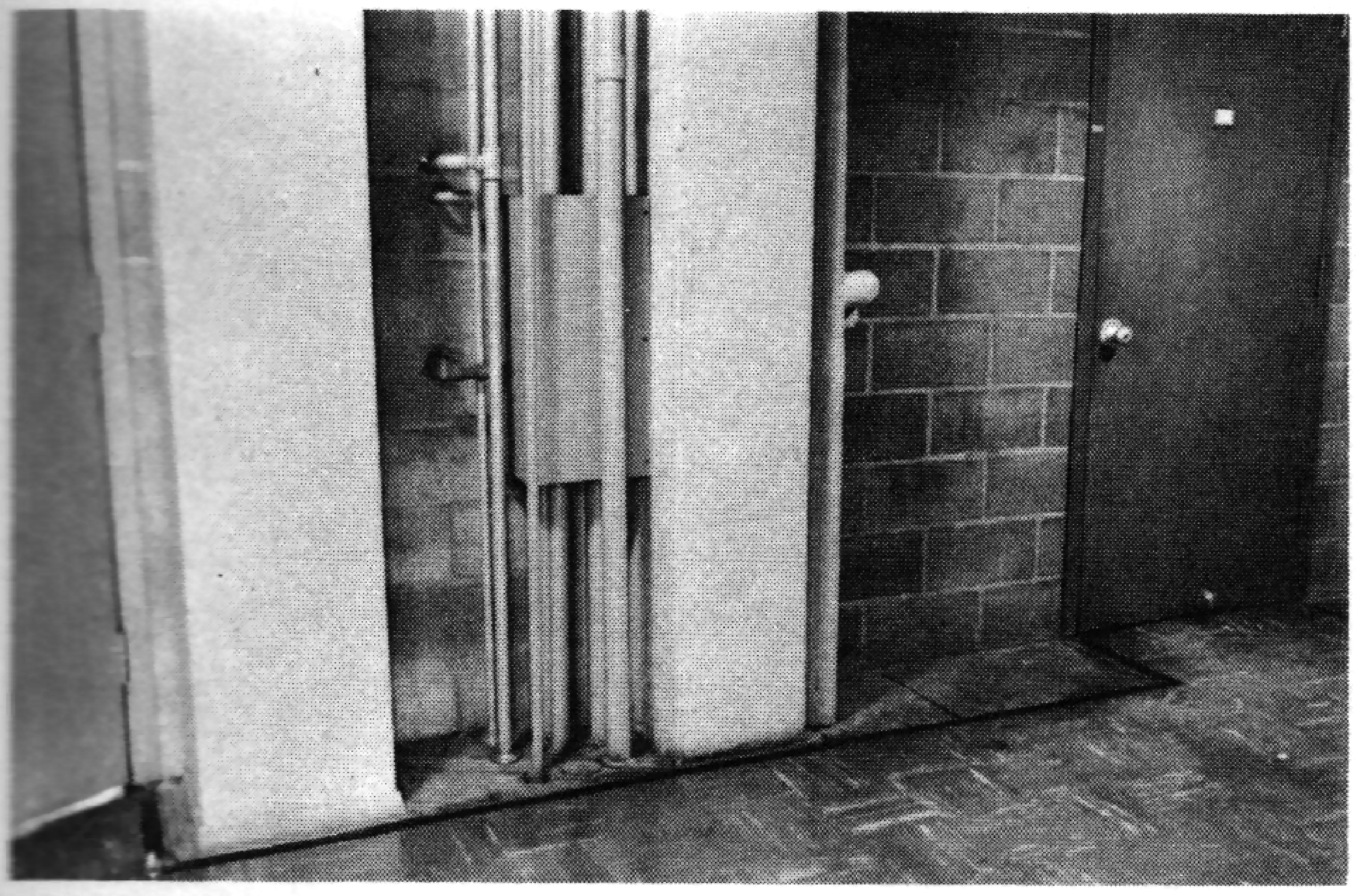
Air conditioning in a physics building is today a necessity and not a luxury. If an air-conditioning system is not to be installed initially, provision should at least be made for its installation at a later date. This has been done for the new Physics Building at the University of Illinois (Chapter 4, Figure 6). All ducts have been installed and lead to a room which has been set aside for the required mechanical equipment.

EXAMPLES OF BUILDING STRUCTURES EMPHASIZING DISTRIBUTION OF SERVICES

Services are brought to laboratories on successive floors in the six-story Josiah Willard Gibbs Research Laboratory at Yale University, from horizontal mains in the basement, by vertical pipes and conduits adjacent to each column on each side of the central corridor, as shown in Figure 9. Columns are spaced at 12-foot intervals and laboratories are 20 feet deep. An area adjacent to each column is reserved for future expansion in services by the provision of a rectangular opening in the concrete slab, normally closed by a concrete cover. Covers can be removed for adding ducts for future ventilating hoods or for bringing up additional services. Pipes and conduits are exposed in the corridors in the first five floors of the building where corridor walls were installed on the laboratory side of the columns. When the sixth floor was finished at a later date, corridor walls were placed so that pipes and conduits rise inside the laboratories.

Laboratory rooms are integral multiples of the 12-by-20-foot building module. How gas, air and electrical services are brought into laboratories through the corridor wall


PHYSICS
BIOLOGY
Up
Elev
UpDn
LOBBY
LABORATORIES
DnUp
Elev
LABORATORIES
UP Dn
Dn
0 10 FEET 50
NORTH
FIRST FLOOR PLAN



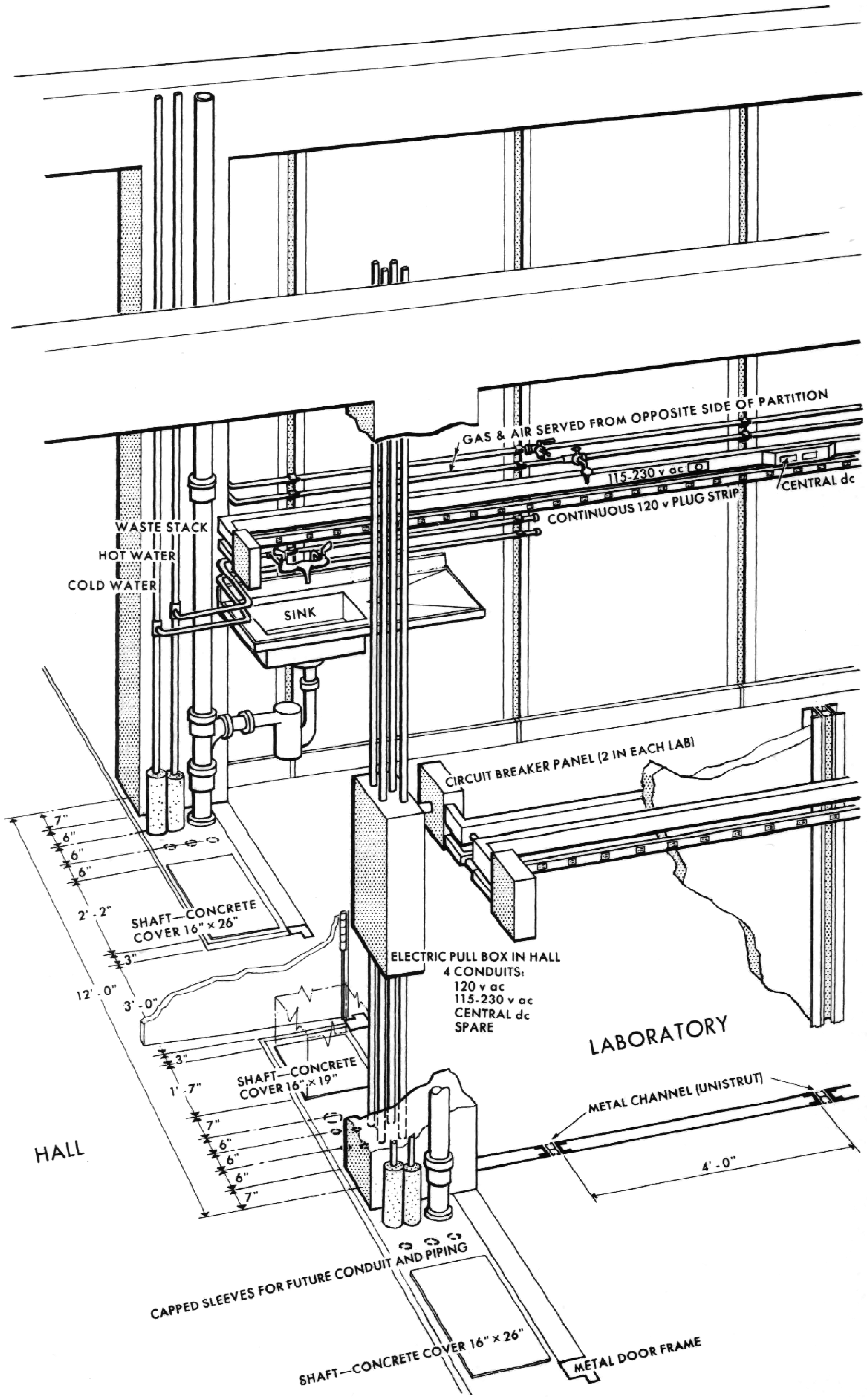

GAS & AIR SERVED FROM OPPOSITE SIDE OF PARTITION
115-230 v ac
CENTRAL dc
CONTINUOUS 120 v PLUG STRIP
WASTE STACK
HOT WATER
COLD WATER
SINK
CIRCUIT BREAKER PANEL (2 IN EACH LAB)
7"
6"
6"
6"
2'-2"
SHAFT—CONCRETE COVER 16" × 26"
3"
12'-0"
3'-0"
ELECTRIC PULL BOX IN HALL
4 CONDUITS:
120 v ac
115-230 v ac
CENTRAL dc
SPARE
LABORATORY
3"
1'-7"
SHAFT—CONCRETE COVER 16" × 19"
METAL CHANNEL (UNISTRUT)
HALL
7"
6"
6"
6"
7"
4'-0"
CAPPED SLEEVES FOR FUTURE CONDUIT AND PIPING
SHAFT—CONCRETE COVER 16" × 26"
METAL DOOR FRAME

Figure 9. View of services in corridor, Josiah Willard Gibbs Laboratory at Yale University. Floor plan, above; perspective, showing method of distributing services, at right. Douglas Orr and Paul Schweikher, Architects, New Haven, Conn.

(for all but the sixth floor of the building) can be seen in Chapter 8, Figure 6.

Laboratory services for the four-story Gordon McKay Research Laboratory at Harvard University are also distributed by vertical risers—located at columns on each side of the corridor, as shown in the floor plans for the building given in Chapter 4, Figure 5. However, the risers are not exposed but are located in vertical shafts, partitioned off by concrete blocks. Openings into the shafts at each floor permit changes to be made. How the mechanical services are brought out from the shafts and into research rooms is shown in Chapter 8, Figure 8.

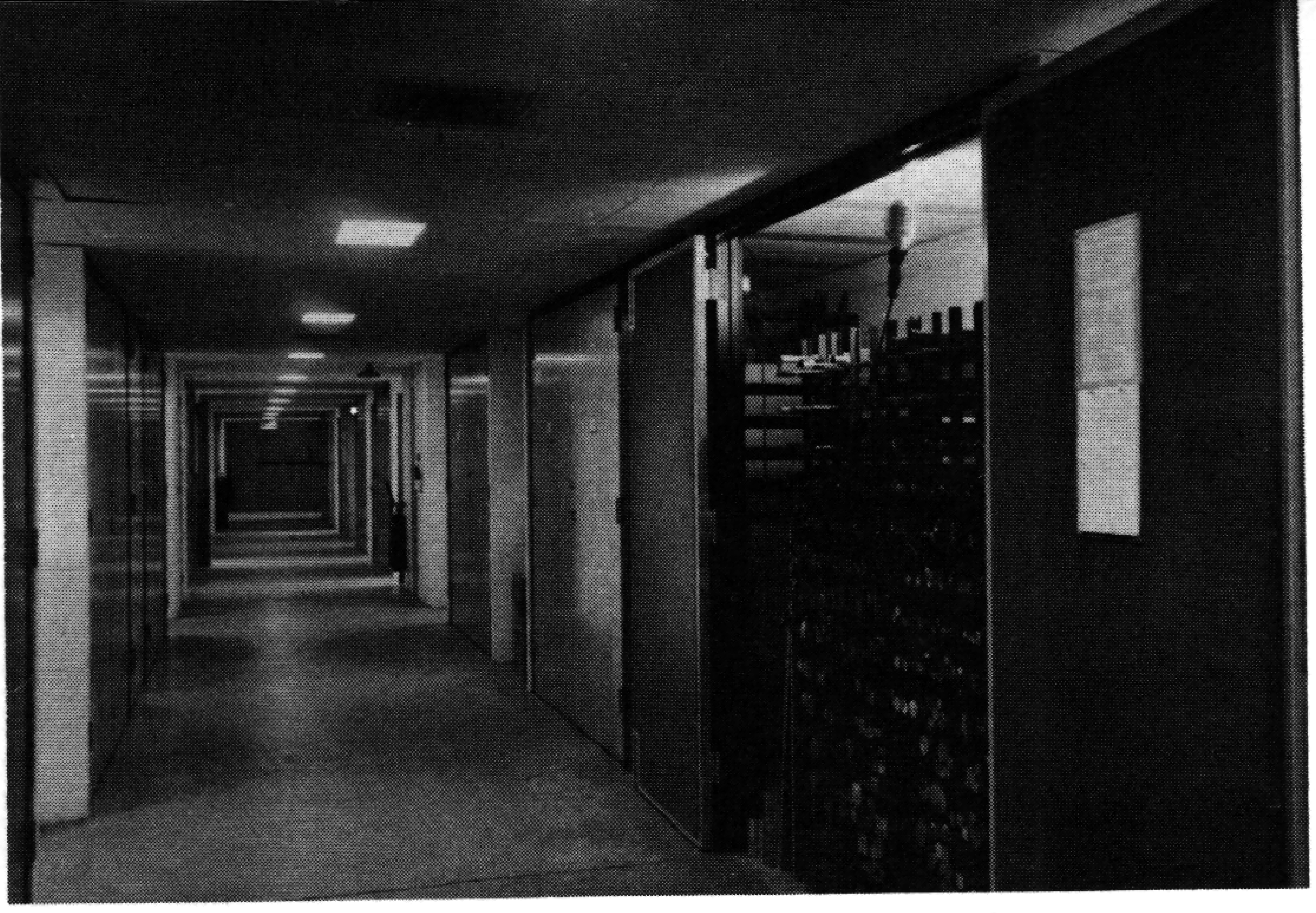


Figure 10. View of corridor, McKay Laboratory, Harvard University (See Chapter 4, Figure 5), showing how corridor walls between service shafts are used for storage cabinets.

Figure 10 shows how storage cabinets installed in the corridors of the McKay Laboratory eliminate the jogs that would otherwise be caused by the service shafts and result in a corridor of uniform width.

Figure 11 shows how services are carried under the ceiling, parallel to the corridor and within laboratory rooms to provide services to laboratories on the floor above, in the Science Building at Drake University. Transverse pipes and conduits are offset vertically into recesses in the concrete ceiling to bring services to benches in the center of the room. The recesses also house 8-foot fluorescent lighting fixtures.

Services are brought up from the basement through vertical shafts on each side of the corridor at Drake. As at the McKay Laboratory, to produce a corridor of uniform width, the space not occupied by these shafts has been used for a number of other purposes. Most of it opens into laboratories and classrooms and is used for storage cabinets and coat racks. The remainder is used in the hallways for display cases and an occasional recessed drinking fountain.

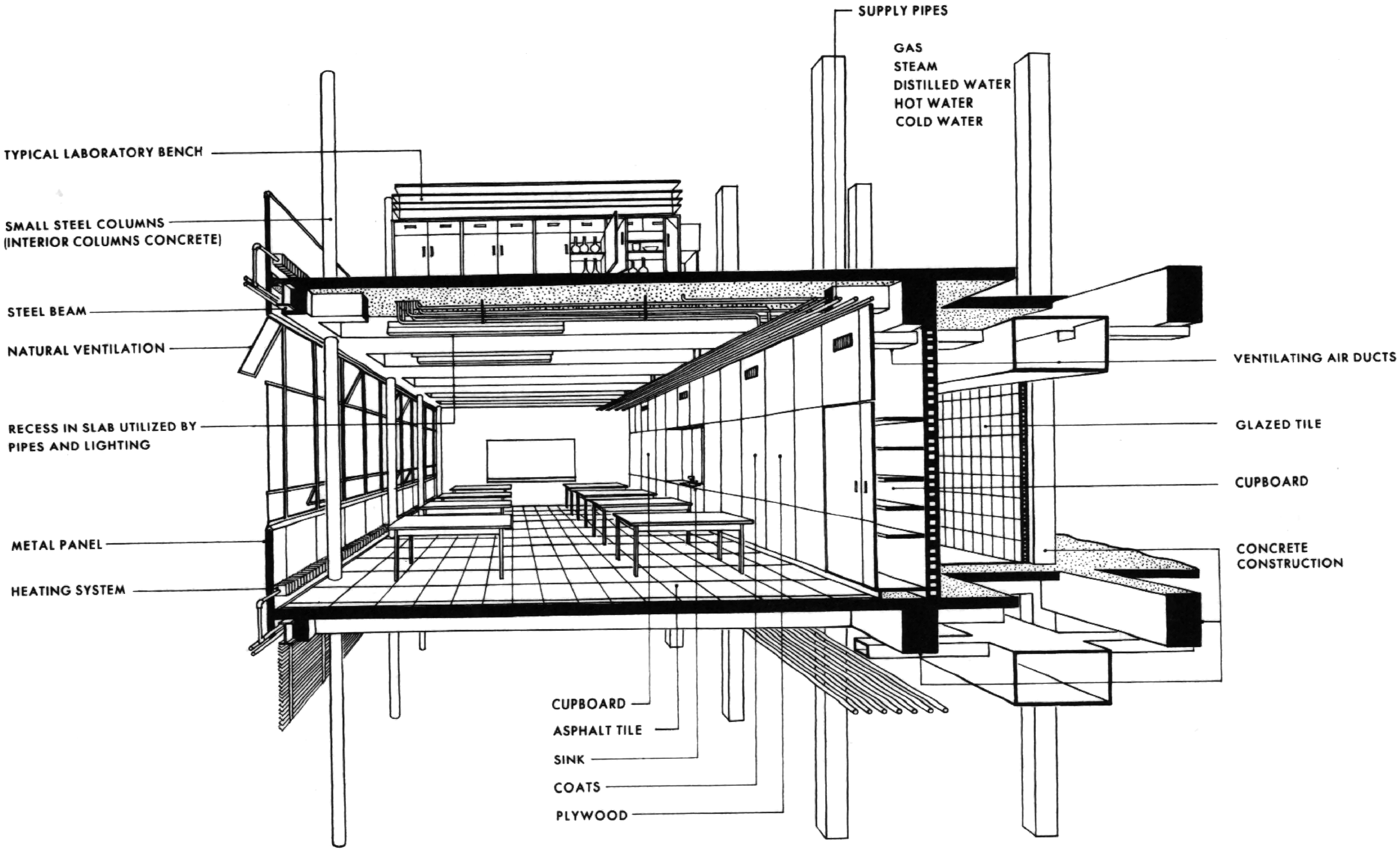
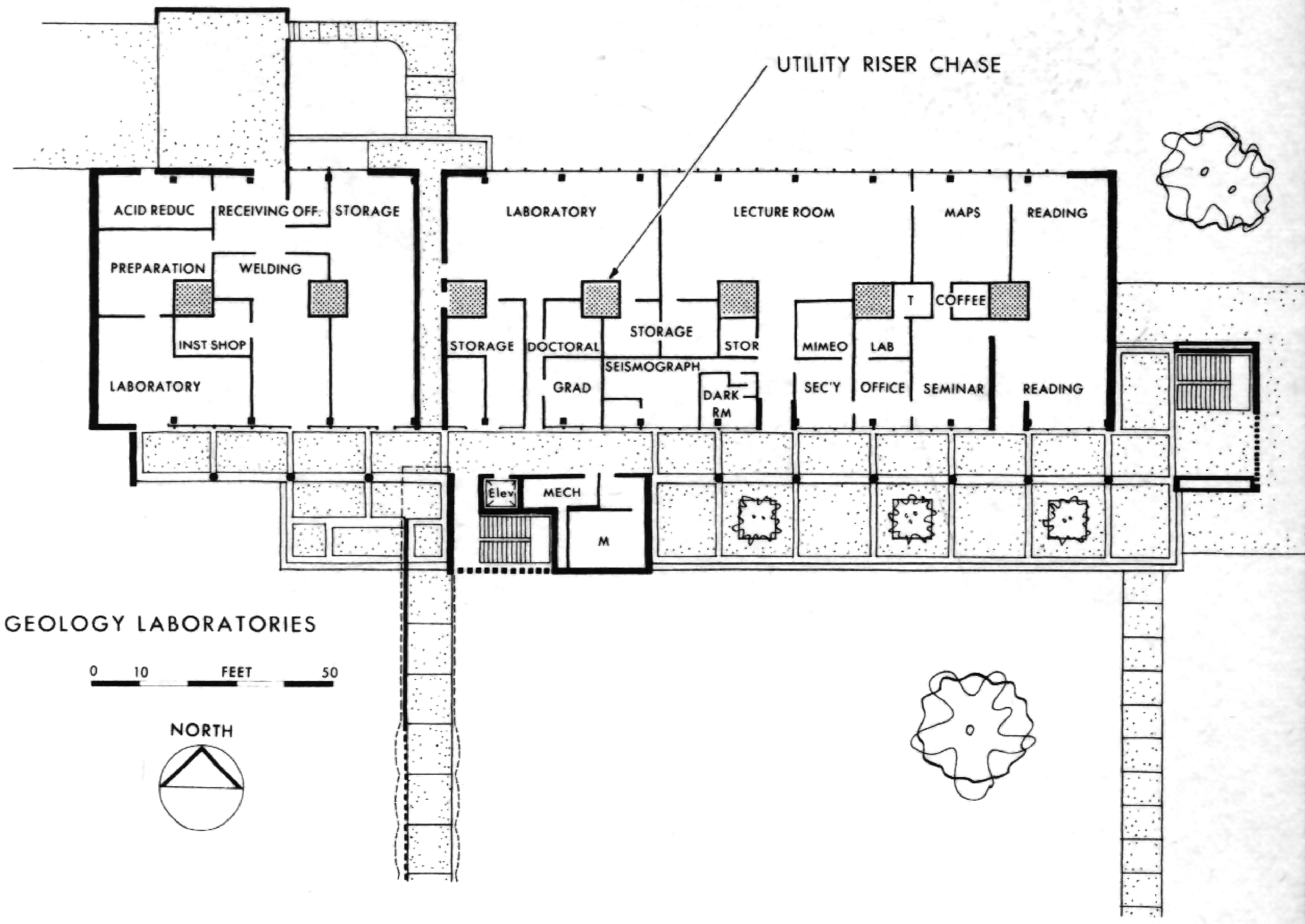

SUPPLY PIPES
GAS
STEAM
DISTILLED WATER
HOT WATER
COLD WATER
TYPICAL LABORATORY BENCH
SMALL STEEL COLUMNS (INTERIOR COLUMNS CONCRETE)
STEEL BEAM
NATURAL VENTILATION
RECESS IN SLAB UTILIZED BY PIPES AND LIGHTING
METAL PANEL
HEATING SYSTEM
VENTILATING AIR DUCTS
GLAZED TILE
CUPBOARD
CONCRETE CONSTRUCTION
CUPBOARD
ASPHALT TILE
SINK
COATS
PLYWOOD

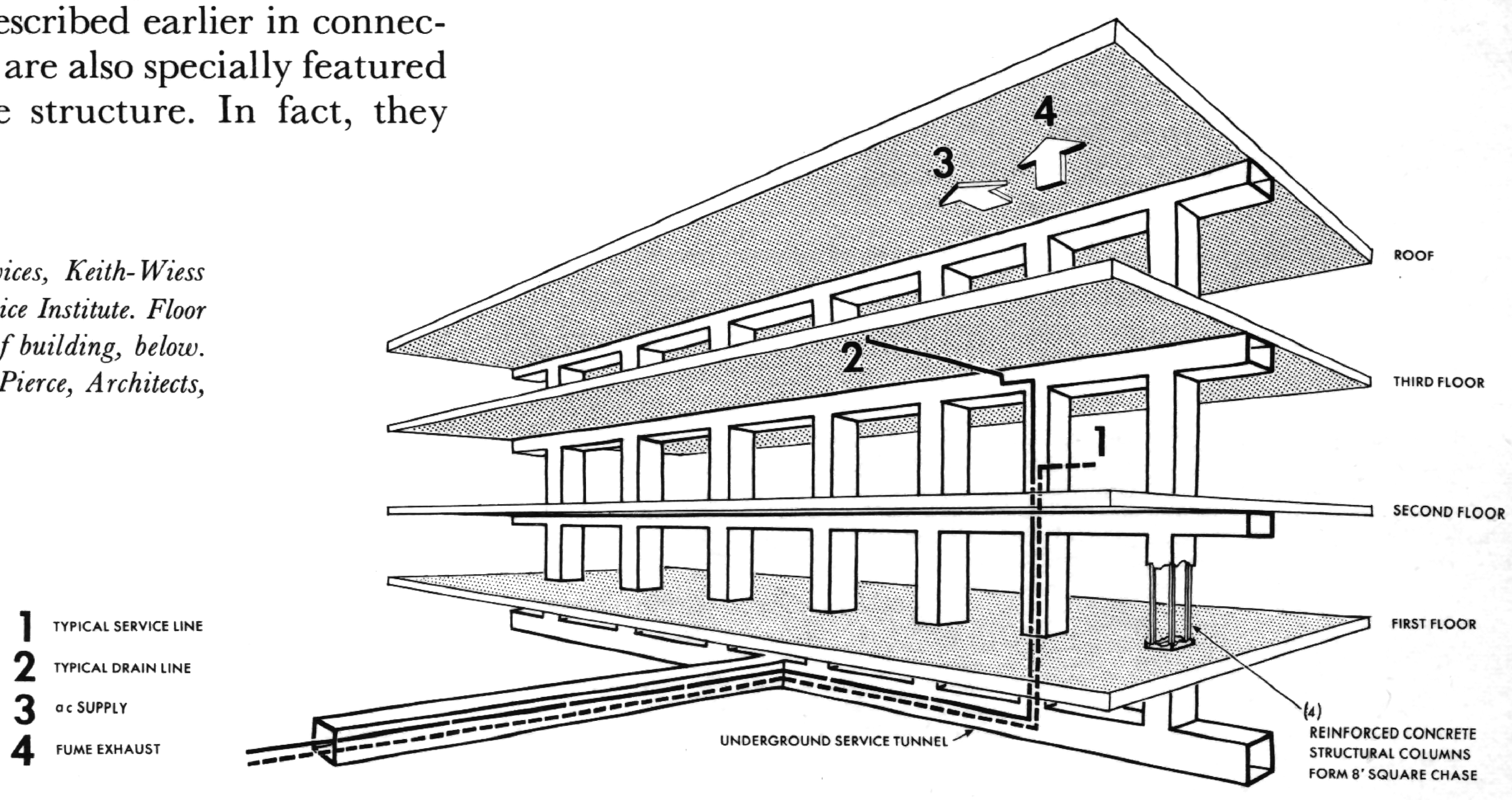
Figure 11. Perspective, showing integration of mechanical and electrical services in the Science Building at Drake University. Saarinen, Swanson and Saarinen, Architects, Bloomfield Hills, Mich.; Brooks-Borg, Associate Architects, Des Moines, Iowa.

The new Geology Building at Rice Institute of Technology, shown in Figure 12, utilizes several interesting design concepts. A companion building for biology uses a similar construction. The principal corridor for each floor is located along one side of the building; and along the axis of the building, instead of a corridor, there are several large (8-by-8-foot) vertical service shafts, spaced 28 feet on centers. Around these shafts, laboratories and other rooms can be built with larger dimensions and more varied arrangement than is possible for a standard center corridor building. The reinforced concrete structural system has been especially designed around the vertical shafts.


UTILITY RISER CHASE
ACID REDUC
RECEIVING OFF.
STORAGE
PREPARATION
WELDING
INST SHOP
LABORATORY
LABORATORY
LECTURE ROOM
MAPS
READING
T
COFFEE
STORAGE
DOCTORAL
STORAGE
STOR
MIMEO
LAB
GRAD
SEISMOGRAPH
DARK RM
SEC'Y
OFFICE
SEMINAR
READING
Elev
MECH
M
GEOLOGY LABORATORIES
0 10 FEET 50
NORTH

The exterior service shafts for the Richards Medical Research Building at the University of Pennsylvania, described earlier in connection with Figure 5, are also specially featured components of the structure. In fact, they

Figure 12. Isometric of services, Keith-Wiess Geological Laboratories at Rice Institute. Floor plan, upper right; exterior of building, below. George Pierce and Abel B. Pierce, Architects, Houston, Texas.


4
3
2
1
ROOF
THIRD FLOOR
SECOND FLOOR
FIRST FLOOR
(4)
REINFORCED CONCRETE STRUCTURAL COLUMNS FORM 8' SQUARE CHASE
UNDERGROUND SERVICE TUNNEL
1 TYPICAL SERVICE LINE
2 TYPICAL DRAIN LINE
3 ac SUPPLY
4 FUME EXHAUST

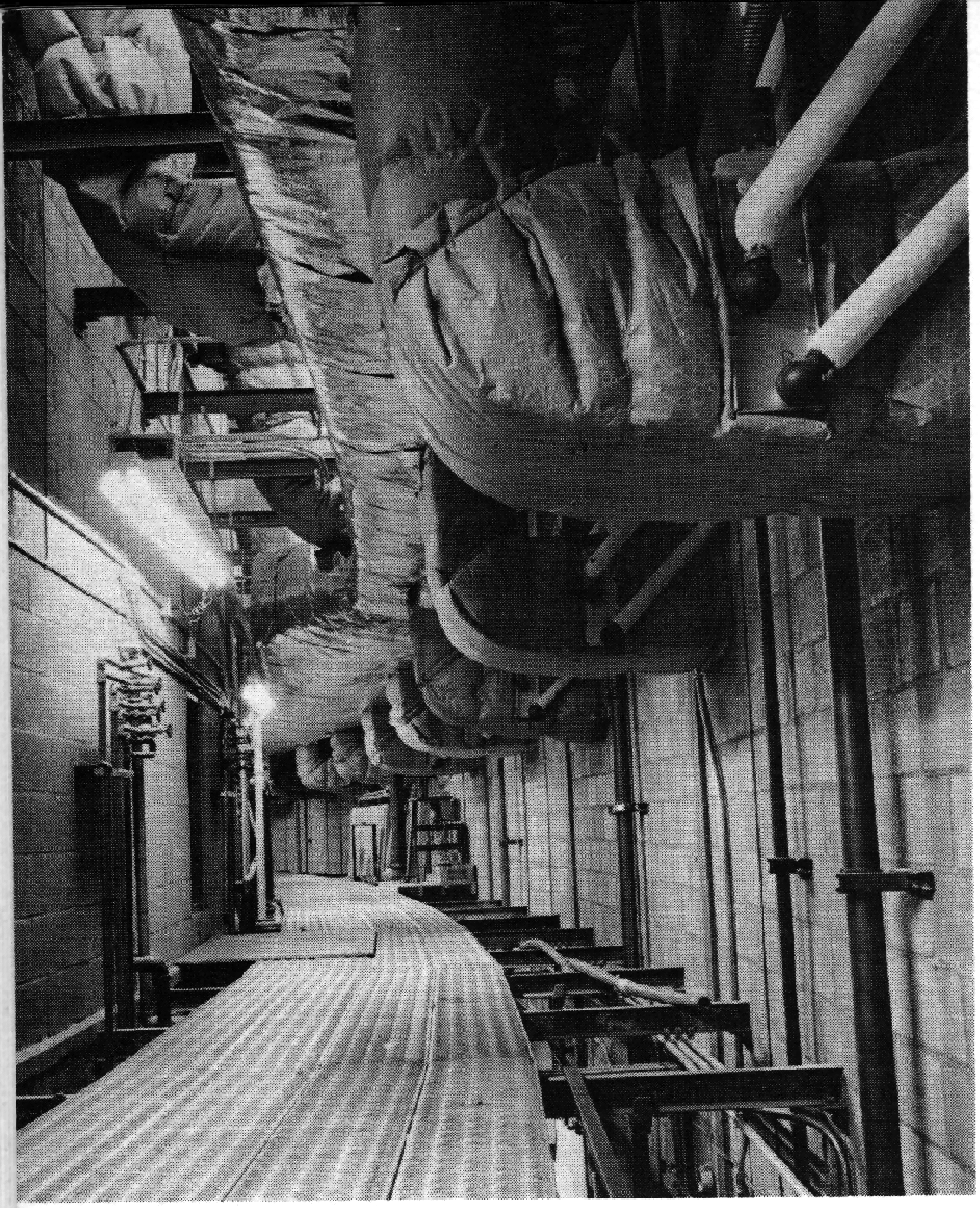
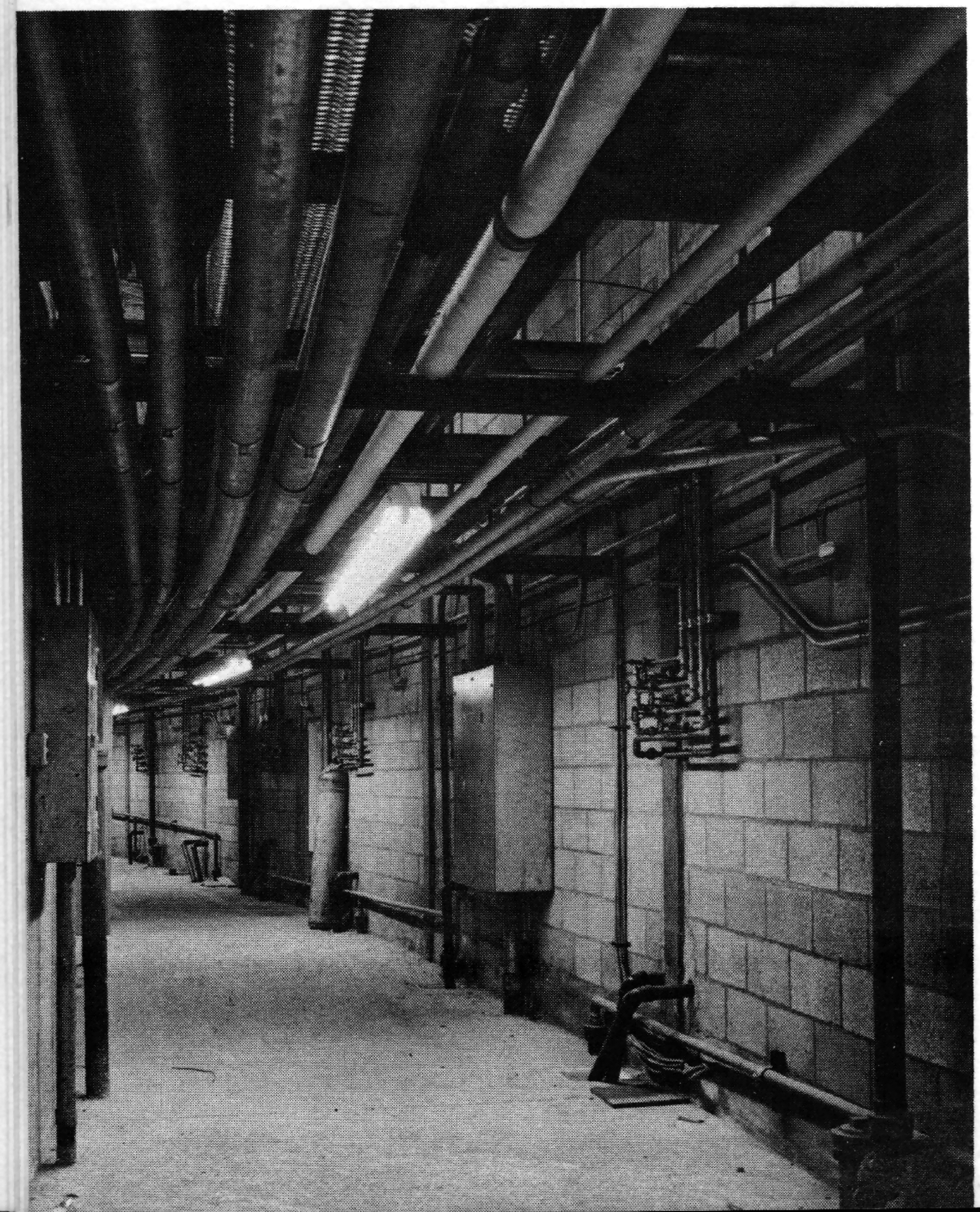


Figure 13. Upper service gallery, mechanical core of General Atomic John Jay Hopkins Laboratory (See Chapter 4, Figure 26). Lower service gallery, shown below. Perriera and Luckman, Architects, Los Angeles.



are the dominant building motif. Exterior shafts are also planned for the new Chemistry Building at the University of California, Berkeley campus. Chemistry and biology laboratories have large demands for air; both intake and exhaust ducts must be large. Thus, large service shafts must be designed to serve these areas in a science building.

Industrial research laboratories such as the General Atomic John Jay Hopkins Laboratory (Chapter 4, Figure 26) and the IBM Research Center (Chapter 4, Figure 27) have more extensive service requirements than colleges and universities. Furthermore, the need for flexibility is greater, and is usually provided by stubbing in the various services at convenient repetitive locations so that any service can readily be provided when needed.

Laboratories are located on each side of a service core which runs the entire length of the General Atomic Research Laboratory shown in Figure 13. The utilities for the various laboratories—gas, air, drain, hot and cold water, distilled water, electric power, and heating and ventilating services—all branch out from mains in the service core and run along the respective laboratory walls. The utilities are stubbed in at 12-foot intervals where laboratory walls may be located. Laboratory modules are12 feet wide by 24 feet long.

The new IBM Research Center (Chapter 4, Figure 27) is a three-story building which achieves its interesting curved form without resorting to non-rectangular laboratories or offices. The building's radius is ample enough in scale to permit adjustment in curvative to be taken up in the glazed exterior corridors and in interior segments between alternating laboratory and office areas. An auditorium and a library each occupy one of these segments. Others are used for service elements such as shops, stairs, and toilets.

As shown in the floor plans (Chapter 4, Figure 27), groups of laboratories are back to back and are separated by a long service corridor wide enough to admit workmen for making changes. Services are brought up through vertical shafts from mains located at terrace level. Bus duct with 600 ampere capacity is used for vertical rise, and 225 ampere bus duct for horizontal distribution along service corridors. Services that can be provided include: cold water, hot water, deionized water, compressed air, vacuum, propane, hydrogen, helium, oxygen, nitrogen, forming gas, waste lines, electrical power, and heating and ventilating services.

The fume hood exhaust system at the IBM Laboratory permits fume hoods to be located at any point in the laboratory room. The exhaust ductwork runs above the suspended acoustical ceiling back to the service shaft and up through the roof. Exhaust fans are located on the roof so all exhaust ductwork is under negative pressure and thus any leaks are *into* the duct rather than out.

BUILDING COMPONENTS

Elevators, Receiving Docks and Hoists

The frequent need to move heavy and bulky loads must be planned for in designing a physics building. A freight elevator is required in a multi-story building. The size and capacity depend largely on the nature of research activity. A 6-by-8-foot cab is usually adequate; the capacity required will likely lie in the range 2000 to 6000 pounds. High speed is not essential for a freight elevator. In fact, low speed may be desirable to discourage unnecessary passenger use. Most college elevators are keyed.

The receiving area of the physics building should have a receiving dock which is accessible to trucks and it should be at truck bed level to simplify loading and unloading. If the receiving area cannot be at this level, a separate movable platform that can be raised or lowered to the desired level can be installed as was done for the Jefferson Physical Laboratory at Harvard. (See Chapter 9, Figure 3).

Hoists and cranes that find use in physics buildings vary all the way from the small ¼-ton chain hoists which have wide use in research laboratories and shops up to the heavy duty hoists supported from movable bridges, required for moving magnets and massive blocks of shielding in accelerator laboratories and capable of handling up to 75 tons. Monorails for supporting movable chain hoists are frequently installed between the receiving area and the shop. They may be carried over certain machine tools to assist in positioning heavy items, as in the physics shop at the University of Florida (Chapter 9, Figure 6), and a branch may run to the freight elevator.

Because of the high cost and possible infrequent need for a permanently installed movable hoist system, alternatives should be given careful consideration. Various sizes of cranes which are mounted on movable dollies and which can be operated hydraulically or by hand are available commercially. Fork lift trucks are also available in many sizes. If only infrequent use is required, they may be borrowed from the Department of Buildings and Grounds, or rented from a a commercial establishment. Professional movers or riggers may even be called in.

A generous distribution of ceiling hooks for supporting chain hoists should be installed in shop and research areas. They should be able to take loads of at least 500 pounds. Heavier loads can be handled by chain hoists supported from girders or from horizontal holes in reinforced concrete beams. Movable "A" frames can also be brought in where needed. Adequate overhead clearance must be provided wherever hoists may be required.

Windows and Exterior Walls

The principal need for windows in buildings in the past has been to provide fresh air and light. Today these needs can be met by artificial means—mechanical ventilation, air conditioning, and electric lighting—which for many areas of the building and for all seasons of the year can provide more satisfactory conditions than can be provided by windows. Furthermore, as will be pointed out in several places in subsequent chapters, large wall areas free of windows are desired for many areas in a physics building. Lecture rooms can be completely windowless; classrooms and laboratories need only a minimum of windows—short, high windows of the clerestory type; offices and shops remain the only areas where windows are quite universally desired.

This all suggests that physics buildings might well be designed with a minimum of window area. However, this is rarely being done. Rather, we have seen an unnecessarily large amount of glass used in a number of new physics buildings. Some of this area has been covered with aluminum foil to reflect the light. Grayed glass has sometimes been installed to absorb some of the light, only to have a large part of the absorbed heat reradiated on into the room. Windows must be provided with shades or venetian blinds to diminish or redirect unwanted light—to minimize glare and to diminish the amount of heat admitted during summer months.

Excess glass is undesirable for other reasons. Glass is a poor insulator, and, therefore, excess glass increases heating costs in the winter and air conditioning costs in the summertime. Excess glass also results in increased maintenance costs for keeping windows clean. All-glass curtain wall construction produces other problems. Tight, sound proof joints are not always made where dividing walls meet glass curtain walls. We have also seen glass curtain walls that are not weathertight and leak water in a driving rain.

Traditional external walls of masonry or concrete are being replaced by curtain walls. Unit-constructed, standardized components for curtain walls are being manufactured with many variations, and are being rapidly perfected as their use becomes more widespread. Besides window glass, components that are available include sandwiches of structural glass, aluminum, porcelain, and a variety of plastic materials. They provide a uniform appearance in the over-all wall and the possibility of accommodating to varying needs—windows where needed and free wall areas elsewhere. Furthermore, these units can be interchanged to accommodate to changing needs.

The principal need for windows in a physics building today is to satisfy one's desire to look outside—to determine the state of the weather or simply to view the landscape or the passing scene. They serve as emergency sources of ventilation and light when artificial sources fail. They also offer a variety of possibilities for architectural design. Surely these needs can be satisfied with less glass than is currently being installed in many new buildings, with resulting advantages both in costs and satisfactory building use.

Venetian blinds provide the best method of controlling and directing the light admitted by windows. Where more complete darkening is required, for optical projection or for certain optics experiments, so-called audio-visual venetian blinds can be installed. These blinds consist of slats which are specially shaped and cut so that adjacent slats touch when the blind is closed. Light-tight channels installed around all four sides of such blinds produce quite satisfactory darkening for most purposes. Audio-visual blinds are available from a number of manufacturers.

Exterior horizontal aluminum louvers that can be adjusted from the inside have been provided on the windows of the new Physical Science Building at Kansas State Teachers College (Chapter 4, Figure 22). The significant advantage of such louvers, as well as other types of exterior shades, is their ability to minimize the amount of direct light which strikes the windows in the first place.

Floors and Floor Covering

The floors of most recently constructed physics buildings consist of poured concrete. In most areas of the building the concrete is either left exposed or covered with asphalt tile. Where ease of maintenance and long life are a consideration, vinyl or vinyl asbestos tile is installed. Ceramic tile is widely preferred for toilet rooms. Exposed concrete floors are usually finished with a hardener or sealer to prevent dusting. The special requirements of floors in certain other areas of the building are discussed subsequently.

Interior Walls and Partitions

Most interior walls in modern buildings are non-loadbearing. In addition to their principal function of dividing space into usable areas which are visually and acoustically separated, the walls in a physics building are called upon to support a variety of devices such as chalkboards, charts, shelves, display cabinets, storage cabinets, bookcases, lines for mechanical and electrical services, and experimental equipment. Examples of such use appear in many of the illustrations in this book.

BLOCK WALLS. The need for stiffness and load carrying capacity has led to the wide use of concrete and tile masonry in non-loadbearing walls. Concrete block partitions, 4 and 6 inches in thickness, are by far the most common of all types. Both first cost and maintenance costs are low. Block walls can fairly easily be torn down and new walls erected elsewhere. The labor required is not so specialized but that it is easily obtainable.

When block walls are tightly constructed they provide adequate acoustical insulation for most purposes. In the case of lightweight, porous, concrete blocks composed of pumice, expanded shale or cinders, a heavy coat of paint or plaster on one surface can decrease sound transmission markedly by filling in the pores. Paint and plaster, of course, have negligible effect on sound transmission when applied to heavy, non-porous partitions. When better insulation is required, walls must be thicker or more massive and, to emphasize the point, they must be well sealed. These and other matters, including the problem of designing sound resistant movable room dividers, have been discussed earlier in the section on Acoustical Design.

MOVABLE PARTITIONS. Prefabricated panels which usually consist of sandwiches of steel and compressed cement-asbestos are widely used for partitions in industrial research laboratories where partitions frequently have to be moved. Such partitions can be moved with less mess and confusion and with much less damage to the materials of the partition than when concrete blocks are used. However, satisfactory commercially available partitions of this type cost in the neighborhood of three times that of concrete block partitions and a stock of spare panels of various sizes must be kept on hand. Thus, when one also considers the relatively rare times that partitions need to be moved in a physics building, even in a research area, the flexibility they provide does not warrant their cost. Prefabricated panel partitions were installed in the original five floors of the Gibbs Research Laboratory at Yale (Figure 9); but it may be significant to observe that when the sixth floor was completed concrete blocks were used for partitions.

Whatever type of partition is selected, it is suggested that lines for electrical and mechanical services within laboratory rooms be surface mounted to the greatest extent possible. Not only is it easier to make changes in services if pipe and conduit are exposed but walls can more readily be changed when necessary.

METAL CHANNELS AND INSERTS. Metal channels such as Unistrut (manufactured by Unistrut Corporation, Wayne, Michigan) and various metal inserts are widely used for supporting service lines and laboratory equipment. Steel channels are usually mounted on the surface of block partitions; less frequently, they are inserted flush with the wall. The panels in the prefabricated walls in the Gibbs Laboratory are supported by vertical channels of Unistrut, flush with the surface of the wall. Figure 9 in this chapter and Figure 2 in Chapter 8 show the effective way in which such channels serve to support service lines and equipment.

Specially shaped metal inserts and hooks embedded in concrete ceilings and in beams also find extensive use for supporting various devices throughout a physics building.

Ceilings

CEILING HEIGHT. The maximum ceiling height in a building is set by floor to floor story height. Savings both in construction costs and in maintenance can be made by keeping this dimension within reason. Slightly over 12 feet is a common and apparently adequate floor to floor height for a physics building. Eighteen representative physics buildings have the following floor to floor dimensions: 12′0″, 11′8″, 14′2″ (one floor only), 12′7″, 12′6″, 12′1″, 12′1″, 12′0″, 13′3″, 12′9″, 13′11″, 13′0″, 11′1″, 11′4″, 14′0″, 11′0″, 12′0″, and 12′6″. The bare concrete ceiling is left exposed throughout most areas in these buildings. Hence most ceiling heights are only 4 to 6 inches (the thickness of the concrete slab) less than the dimension given.

SUSPENDED CEILINGS. Suspended ceilings, normally of acoustic tile, are usually installed in offices, conference rooms, and corridors. The lowered ceiling gives a more pleasing effect in small rooms, and, in corridors, serves to hide the service lines and air ducts which may be mounted near the ceiling. The tile panels are usually supported by a lightweight grid consisting of aluminum T-bars. Long rectangular panels should be used in corridors so that when individual panels are removed for working on service lines, larger openings are provided. There are some advantages in design in integrating the light fixtures with the suspended ceilings. In the section on Acoustical Design we have already discussed the problem of sounds transmitted through the open space above suspended ceilings when dividing walls are not carried through to the structural ceiling.

Suspended ceilings in lecture halls and the need for their acoustic treatment and the acoustic treatment of ceilings in other rooms will be discussed in subsequent chapters.

Corridors and Stairways

Corridor floors are usually covered with asphalt tile, though the longer life and better maintenance characteristics of vinyl asbestos tile make its installation economically reasonable despite its higher initial cost. Because of its excellent wearing characteristics, terrazzo is frequently used for corridor floors and stairways, especially in the vicinity of entrances to the building. However, the noise produced by walking upon terrazzo is such that the softer asphalt or vinyl tiles should preferably be used in the vicinity of classrooms and lecture rooms.

Stairs are usually made of concrete with carborundum and metal inserts at the front edge of each step to provide an abrasion-resistant non-slip surface. Since heavy objects are occasionally moved up and down stairs, these inserts must be well secured to prevent them from loosening. Similarly, hand rails should be so designed and secured that they can withstand rough service.

The lower portion of corridor walls should be easily cleanable, for they are subject to much abuse, including the thoughtless damage caused by rubber heels of students leaning against the walls. A glossy enamel paint can be washed but soon wears off. A wainscot of ceramic tile is easier to clean, wears well, and can be attractive; if the corridor walls are constructed of concrete blocks, the lower blocks may be coated with one of the newer baked-on epoxy resins. A black rubber base strip is sometimes installed at the floor, or the wall painted a darker color or darker tile used near the floor, to mask marks left in cleaning and polishing. This treatment is many times carried into classrooms and other areas of the building.

The corridor on the main floor should be about 10 feet wide. Corridors on upper floors where traffic is less need be only 8 feet in width.

CORRIDOR DEMONSTRATIONS. Metal channels should be mounted on certain of the corridor walls of a physics building or some other device be provided for the temporary support of charts, demonstrations, and experimental apparatus so useful for student learning. Convenience outlets for 120 volts ac should be available at frequent intervals. Some section of the corridor wall should be set aside for display cabinets. They should be located in the line of student traffic and yet not where there is apt to be congestion, such as in the immediate vicinity of the main lecture room. Display cabinets should be provided with electric power, both for lighting and to furnish power for the displays. Display cabinets can well be both of the closed and open types—closed cabinets that can be locked for displays not to be tampered with, and open cabinets for equipment that invites experimentation.

Several bulletin boards may be required, including one in the vicinity of the main departmental office for posting general notices and one in the vicinity of the elementary laboratories for posting laboratory schedules.

Corridor Coat Racks. Extra coats and books are a nuisance in laboratories and classrooms. Some colleges provide coat and book racks in the corridors. Figure 14 shows such racks in the corridor adjacent to the Freshman Physics Laboratory in the new duPont Science Building at Swarthmore College.

Coat hangers should be of the type which can be removed from the rack. A coat can then be easily placed on the hanger, even while the student holds books under one arm. If the hanger is permanently attached to the rack, books must first be laid down and both hands used. To be sure, loose coat hangers will disappear, but their cost is small and the rate of disappearance will diminish as dormitory closets become adequately stocked.

The disappearance problem can be solved by using any one of the special hangers which do not have conventional hooks but which nevertheless can be removed from the rack to simplify their use. Several types are sketched on Figure 14. Such hangers fit only the type of rack for which they are designed and are hence less apt to be carried away.

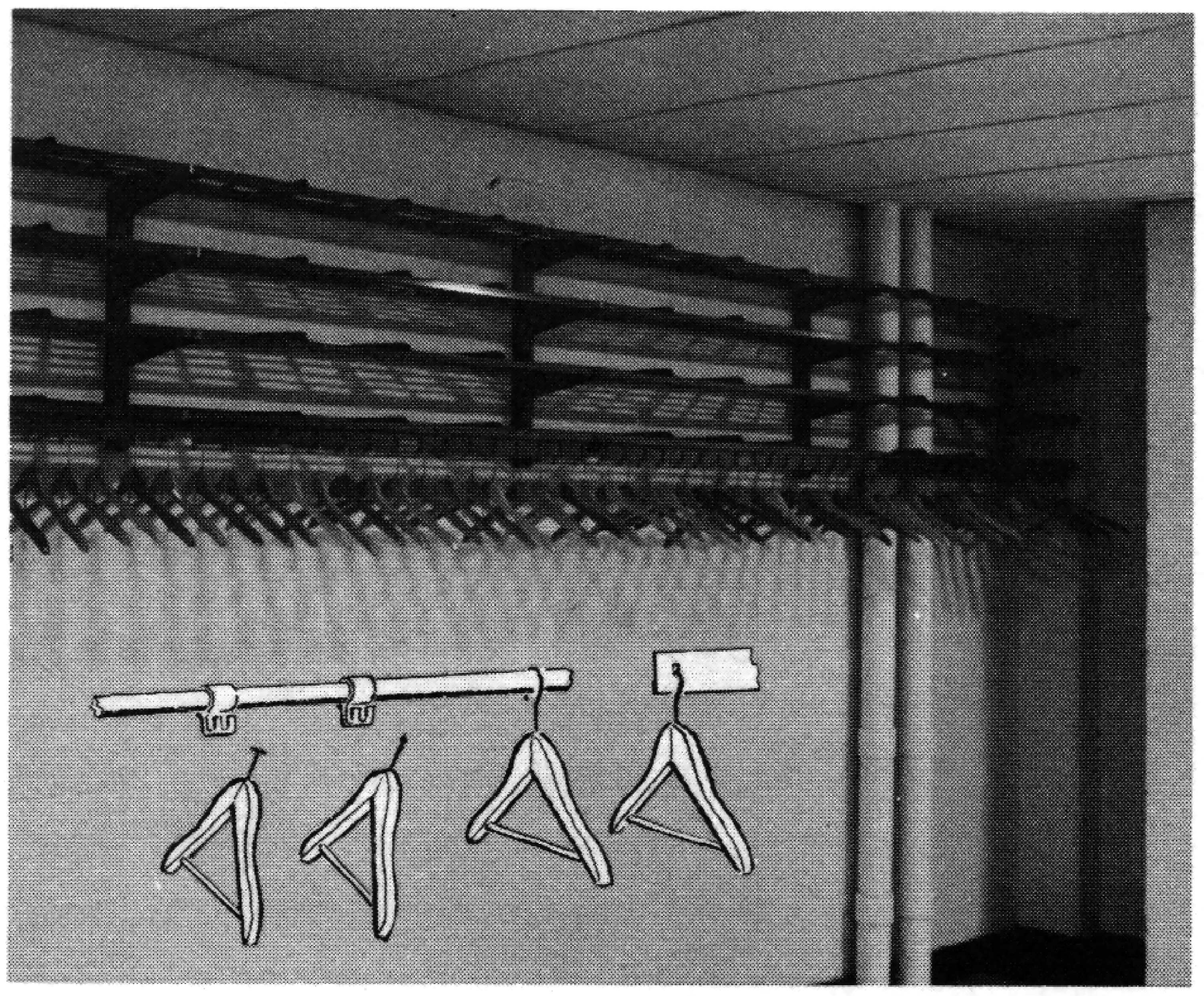


Figure 14. Coat racks are installed in the laboratory corridor of the new duPont Science Building at Swarthmore College (See Chapter 4, Figure 25).

Corridor Storage. Attention should be called to the effective use of corridors for storage in the McKay Laboratory at Harvard (Figure 10) and in the new Physics Building at the University of Illinois (Figure 4). As described earlier, the storage cases are built into the corridor wall in the McKay Laboratory. They occupy space that was left over after the space required for vertical risers had been assigned. The storage cases at Illinois are free standing cases, and are arranged along one side of each of the two interconnecting cross corridors. (See Chapter 4, Figure 6).

Doors

Doors and door frames in physics buildings need to be able to take hard usage. The typical door is a solid or hollow core wood door, and it is hung in a metal frame. Door dimensions should ordinarily not be less than 3 by 7 feet. Double doors are required for some rooms; such as, the lecture room, shop, and some laboratory rooms. Push plates and kick plates should be provided on doors where abrasion is likely.

The direction of door swing is important. Most codes require doors to swing outwards for rooms to be occupied by more than a certain minimum number of persons. This would include lecture rooms, classrooms, and sometimes teaching laboratories. Where codes do not apply, the direction of swing should be determined by individual need. Where doors that swing outwards are mounted flush with the corridor wall, hinges should be attached in such a manner that when the door is left open it can stand against the corridor wall.

Where corridors have double walls to provide vertical riser space for services, doors can be recessed. They will then not project into the corridor when they are opened.

Since rolling carts are extensively used for transferring equipment from room to room in a physics building, raised thresholds should not be installed in any of the doorways.

Exterior doors should be protected from the weather, either by recessing them or by providing an overhanging protection.

Hardware, Locks and Keys

Only heavy duty, well-constructed hardware should be installed in a physics building. There is no economy in using the lightweight hardware that is competitively designed for domestic house construction. Corrosion resistance is also required of hardware used in some areas, such as the chemical preparations area.

Certain economies, however, can be made by installing only the type of hardware that is required. For one thing, not all doors require locks. Latch sets (simple knob and catch mechanisms) are adequate for many doors, such as those for classrooms and toilets. They are much cheaper than lock sets and can be obtained to match the latter in both appearance and durability. Doors which have closing mechanisms do not even need latch sets; push plates and pull handles are sufficient. When closures are installed at the tops of doors they should be of the type that move with the door. The bracketed closure is a hazard to tall persons. Door closures are expensive and hence should be installed only on doors which require them.

The keying for a building should be given careful thought so that authorized persons need to carry only a limited number of keys. The locks on the doors throughout the building should be such that they can be opened by a single master key, with the possible exception of those rooms that for reasons of security or hazard require special locks. It should be possible to operate the locks on rooms which have related functions by means of a submaster key and, finally, certain keys should be provided which open only certain locks.

EQUIPMENT

Chalkboards

Chalkboards and chalk are as necessary for instruction in physics as paper and pencil. This suggests that quality rather than low first cost should determine the selection of chalkboard materials. Slate is regarded by many physics teachers as the most desirable material for chalkboards. However, we have seen chalkboards of steel and of glass which also have excellent writing and erasing characteristics. Likewise, some composition boards have good surface characteristics; where they fail is in durability. We have seen composition boards which have had to be replaced within two years. High quality steel and glass boards are "guaranteed for the life of the building"—a life equally possible for slate.

However, not all steel, glass, or even slate, durable as these may be, have satisfactory writing and erasing characteristics. The surface must be rough enough to take chalk but not so rough or porous that it cannot be easily erased. We suggest that samples of the materials be submitted at the time of bidding.

Only top-quality chalkboards should be

installed in lecture rooms and classrooms where they are subjected to continued use. The cheaper composition chalkboards are satisfactory for portable boards and for offices and other areas where use is only occasional.

Double and triple chalkboards with moveable sections are being widely installed in lecture halls to provide the needed chalkboard area. These systems are discussed in detail in Chapter 5.

There is no agreement as to the most desirable color for chalkboards. Green chalkboards were first introduced largely for aesthetic reasons. Blue chalkboards are now available. There is some reason to believe that the prolonged reading from such boards results in less eyestrain than from dead black chalkboards, providing the color is chosen to provide a reflectance in the neighborhood of 15%. Since black chalkboards are soon gray—and are easier to erase if left gray and not washed—the noticeable difference in eyestrain between black and colored installations is probably negligible. We have had complaints from users of light green and light blue chalkboards because they gave insufficient contrast to white chalk.

The best chalk to specify for all chalkboards is 95% pure white calcium carbonate of medium hardness, with only 5% binder. Poor grades of chalk may contain as much as 50% clay which not only makes the board difficult to erase but also is injurious to the surface. So-called sight-saving yellow chalk has sometimes been recommended for green chalkboards. However, tests have shown that greater visibility is provided by white chalk.[10] Most colored chalk is difficult to erase because pigment gets in the pores of the board.

Manufactured chalkboards can be reconditioned with chalkboard paint, available from chalkboard manufacturers. When slate becomes rough and grayed by chalk embedded in its surface, it can successfully be resurfaced by sanding down; however, care is required to get the correct degree of roughness.

Laboratory Furniture

The furniture required in a new building should be decided upon during the early planning stages for the building. The desired arrangement of furniture and other equipment in a room frequently determines the best shape and size for the rooms and also the location of doors and windows. It may also determine how building services and laboratory services can best be provided, not only where outlets should be located within each room but also how best to route the services throughout the building.

Two measures will help in promoting the flexibility which physics buildings require: first, in selecting furniture, the number of kinds and sizes of furniture units adopted should be strictly limited; second, the installation of furniture and its integration with utilities should be such that changes can be made with a minimum of effort.

By a consideration of the needs of the various laboratories, and with some give and take on the part of those who feel they require special furniture, it will usually be found that most furniture needs can be satisfied by adopting a limited number of standard lengths for all furniture units, for example, 4- and 6-foot nominal length benches, work benches, tables, underbench cabinets, and wall cases. Two or three alternative widths might reasonably be permitted. By "width" is normally meant the front to back dimensions; however, some manufacturers call this "depth," and a few even call it "length." When only a few standard-length units are used, one type of unit can more readily be exchanged for another, and repairs are simplified as well. Where a number of shorter units are used in place of a long custom-built table or base cabinet, the cost of the unnecessary duplication of legs or end partitions in adjoining units is generally more than offset by the lower cost of the standard units. However, the principal advantage of using standard units remains their greater flexibility.

A continuous work surface, perhaps along

Table IV. Laboratory Table Top Materials and Identification by Various Trade Names—1960

DESCRIPTION See Note 2	HAMILTON	KEWAUNEE	LAB FURN CO	METALAB	PETERSON	SHELDON
Natural stone, impregnated, jet black finish	IMPERIAL STONE	KEMROCK	LABROCK	METROCK		SHELROCK
Pressed wood fiber, laminated plies tempered, jet black finish (See Note 3)	HAMILCOR (4 ply) HAMILINE	KEMWELD (6 ply)	LABWELD LABCRAFT (3 ply)	FIBREWELD	WELDED FIBRE (6 ply)	BLACK PLYWELD (6 ply) BLACK SHELCRAFT Same as Plyweld with plywood core
Pressed wood fiber, laminated plies tempered, green finish	HAMILTONE—GREEN (4 ply)	GREENWELD (6 ply)		COLORWELD or COLORCORE (3 ply)	GREEN WELDED FIBRE (6 ply)	GREEN PLYWELD
Pressed wood fiber, laminated plies tempered, gray or gray and brown as noted with manufacturer's trade name	HAMILTONE—GRAY (4 ply) gray	GRAYWELD gray (6 ply)		COLORWELD gray & brown COLORCORE	GRAY WELDED FIBRE (6 ply)	GRAY PLYWELD
Birch or other hard wood, laminated strips, black finish as noted under manufacturers trade name	HAMILCOTE (maple) EBONACID carbonized	BIRCH KEMBLACK	LABCOTE resinous fin. CARBONIZED BIRCH carbonized		B.A.R. CARBONIZED	CARBONIZED WOOD
Birch or other hard wood, laminated strips, clear lacquer finish						
Composition stone, Transite, asbestos fibers, Portland cement, formed under pressure, unlaminated. (See Note 4)	SOLID COMPOSITION STONE	TRANSITE	LABITE	LABRASTONE	TRANSITE/or COMPOSITION STONE	SHELDINE
Composition stone, Colorlith, asbestos fibers, Portland cement, chemical resistant colorings and fillers, formed under pressure, unlaminated. (See Note 4)	COLORLITH charcoal gray HAMILITE charcoal gray special baked fin.	KEMSTONE charcoal gray Colorlith COLORLITH green or brown	NUROCK charcoal gray	CHEMLAB charcoal gray CHEMSTONE COLORLAB green or brown	LABSTONE brownish black COLORLITH green or brown	COLORLITH charcoal gray, green or black SHELSTONE gray-black special baked fin.
Plastic laminated on backing (Formica, Micarta, Panelyte, Textolite)	HAMILTEX	PLASTIC	PLASTIC	VINYLCRAFT	PLASTIC	

Natural stone, Alberene stone, (soapstone)

quarried in Virginia, homogeneous silicate
without lamination or stratification.
Two grades:
Regular grade, with talc, blue gray,
mod. rupture, any direction, min., 1500 psi,
abrasive hardness Bur. Standards min. 4.5;
absorption water (48 hrs) by wt. max. 0.20%.
Grade 25, without talc, dark blue black,
mod. rupture, any direction, min., 3000 psi,
abrasive hardness Bur. Standards min. 15.0;
absorption water (48 hrs) by wt. max. 0.10%.

Stainless steel, 18–8, (18% chromium, 8% nickel),

Type 302 most common stock for sinks and bench tops is rust resistant, not corrosion-proof.
Type 316 is recommended for corrosion resistance, e.g. chemical and photographic processing equipment.

Manufacturers (See Note 1):
Hamilton Manufacturing Co., Two Rivers, Wisc.
Kewaunee Manufacturing Co., Adrian, Mich.
Laboratory Furniture Co., Mineola, N. Y.
Metalab Equipment Co., Hicksville, Long Island, N. Y.
Leonard Peterson and Co., Inc., 1222 Fullerton Avenue, Chicago 14, Ill.
E. H. Sheldon Equipment Co., Muskegon, Mich.

NOTES
1. Names of lab equipment manufacturers shown are representative; others not listed can supply competitive materials.
2. Thickness—all tops 1¼″ unless noted.
3. Number of plies—varies, 5 unless noted.
4. Transite and Colorlith are trade names as manufactured by Johns-Manville Corp.

one side of a laboratory, can be supported by standard-length base frames or base cabinets. The length of the work surface does not need to be an integral multiple of the length of the standard units, for open spaces should be left at intervals to provide knee spaces for persons seated at work.

In small side rooms such as are associated with optics laboratories, the furniture can perhaps most efficiently be built in. The size of the room and its use is usually such that little change can or will likely be made in furniture arrangement. Instead of tables, work surfaces for such small rooms can be supported by brackets or cleats from the walls to eliminate the difficulty of sweeping around table legs.

Where changes in furniture may subsequently be required, laboratory services should not be integrated with the furniture. The use of service islands, preferably at the walls of the laboratories as described in subsequent chapters, eliminates the necessity of attaching utility outlets to laboratory tables and benches. Furthermore, where furniture needs to be fixed in position, the method of attachment should be such that the furniture can be removed with a minimum of damage to either the building or the furniture.

Manufacturers of laboratory furniture have acquired a thorough understanding of the needs of science laboratories for furniture that is both functional and durable. Their representatives can be helpful in suggesting furniture types and sizes and in planning laboratory layouts, and they are willing to do so with no obligation on the part of the prospective client other than that their product be considered. The advantage of using templates on drawings made to scale, when planning furniture or equipment layouts, has been emphasized earlier.

A variety of top materials is used for work surfaces in physics laboratories and shops. Table IV lists some of the more widely used materials and, in connection with each, gives the trade name under which a comparable material is supplied by a number of manufacturers. Since resistance to corrosion is a less significant characteristic than resistance to impact and abrasion, hardwood tops of birch or maple (narrow strips glued together to prevent warping), and pressed wood fiber are the two materials most widely used in physics laboratories. Laminated plastics are well suited as tops where less heavy duty is required. Stone or composition stone and stainless steel are usually reserved for the vicinity of sinks.

Manufacturers of laboratory furniture can supply either steel or wooden furniture and both types are widely used in physics laboratories. The prices of steel and wooden furniture are competitive. Manufacturers of steel storage cabinets and shop benches can also supply useful items for physics laboratories.

When preparing specifications of laboratory furniture for bidding one should avoid a description which includes the phrase "or equal." The term is too indefinite and may open the door to substitutions which are not desired. Rather, one should tighten his specifications to include all the significant features of construction. This requires that one study the features of construction of several manufacturers and select the features of one for detailing in the specifications. One should not select the "best" features of different manufacturers, for this could well lead to incompatibility of design. On the other hand, different manufacturers can and do match the construction features of their competitors.

Laboratory furniture is sometimes constructed locally. This is frequently true for storage cases and benches which are built-in as part of the building. Some institutions build their own laboratory tables and benches, using commercially available steel legs or a frame constructed of ordinary steel pipes. Tops usually consist of strip birch or maple which is given a clear finish. Solid flush doors and plywood boards are also used for tops, in which case they can be surfaced with pressed hardboard or a plastic laminate.

4. Floor Plans

INTRODUCTION

The floor plans presented in this chapter have been selected to illustrate a number of building types and a range of building sizes. The first 15 buildings presented are primarily physics buildings though at least two of them also provide space for mathematics. The second group consists of ten science buildings —buildings in which the space is shared between physics and one or two other sciences or engineering. These are followed by the floor plans of four industrial research laboratories. The final group consists of plans for buildings in the design stage.

References are made in other chapters to a number of the features displayed by the floor plans in this chapter.

The buildings presented are listed below according to group and figure number.

Physics Buildings

1. LeConte Addition, University of California, Berkeley, California
2. Catholic University of America, Washington, D. C.
3. University of Florida, Gainesville, Florida
4. University of Georgia, Athens, Georgia
5. Gordon McKay Laboratory, Harvard University, Cambridge, Massachusetts
6. University of Illinois, Urbana, Illinois
7. University of Liverpool, Liverpool, England
8. University of Maryland, College Park, Maryland
9. Karl Taylor Compton Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
10. Ohio State University, Columbus, Ohio
11. Pomona College, Claremont, California
12. Spring Hill College, Mobile, Alabama
13. University of Virginia, Charlottesville, Virginia
14. University of Wichita, Wichita, Kansas
15. Worcester Polytechnic Institute, Worcester, Massachusetts

Science Buildings

16. Brandeis University, Waltham, Massachusetts
17. Brigham Young University, Provo, Utah
18. Colorado State University, Fort Collins, Colorado
19. El Camino College, El Camino, California
20. Grinnell College, Grinnell, Iowa
21. Illinois Institute of Technology, Chicago, Illinois
22. Kansas State Teachers College, Emporia, Kansas
23. University of Kansas, Lawrence, Kansas
24. Oklahoma State University, Stillwater, Oklahoma
25. Swarthmore College, Swarthmore, Pennsylvania

Industrial Buildings

26. General Atomic John Jay Hopkins Laboratory, San Diego, California
27. International Business Machines Research Center, Yorktown, New York
28. Pan American Research Center, Tulsa, Oklahoma
29. Varian Associates, Palo Alto, California

Buildings in Design Stage

30. Architectural Student Design Study, Barry N. Merenoff, College of Architecture, University of Michigan
31. The H. C. Oersted Institute, University of Copenhagen, Copenhagen, Denmark
32. Proposed Physics Facilities, Rutgers University, New Brunswick, New Jersey
33. Proposed Physical Sciences Lecture Hall, University of California, Berkeley, California

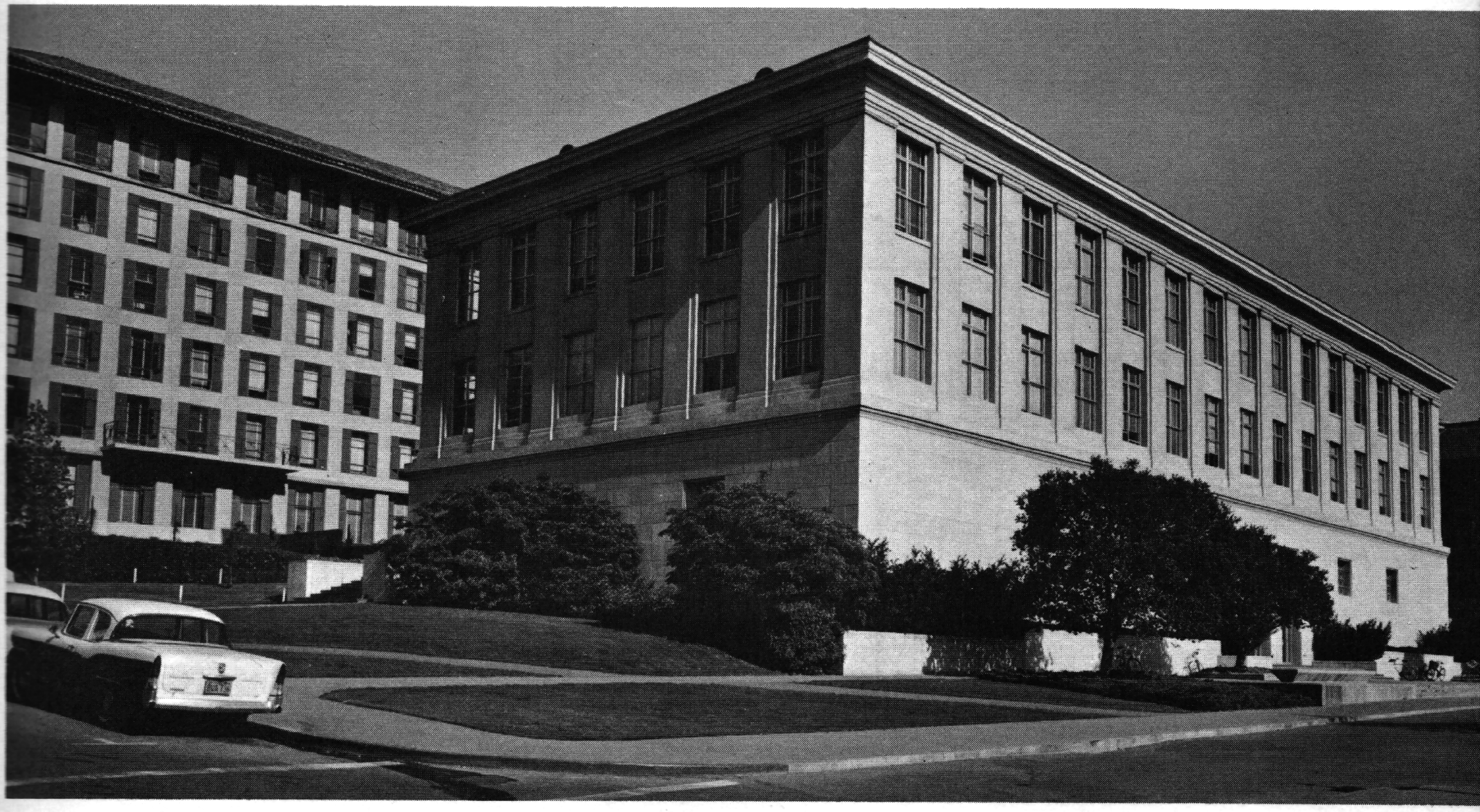
1.

LeConte Hall Annex
University of California
Berkeley, California

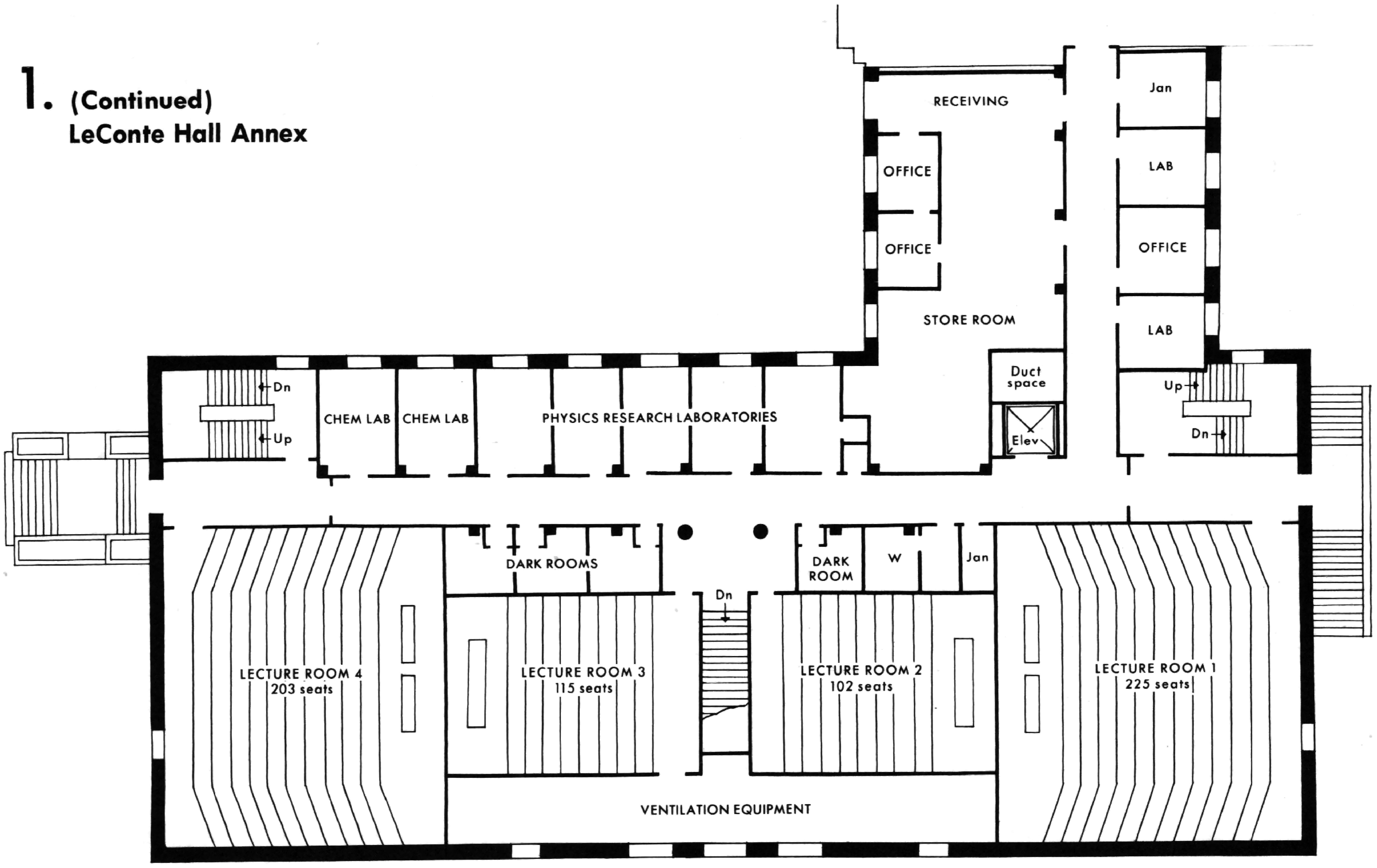
Architects:	Miller and Warnecke (now Warnecke & Warnecke) Oakland, California
Completed:	1950
Gross Area of Building:	66,330 sq. ft.
Total Cost of Building:	$1,250,000*
Air Conditioning:	None

* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

View of northwest corner of building showing main entrance at right. This wing addition houses four sloping lecture rooms on the lower levels. (See following pages for floor plans.)



1. (Continued)
LeConte Hall Annex


RECEIVING
Jan
OFFICE
LAB
OFFICE
OFFICE
STORE ROOM
LAB
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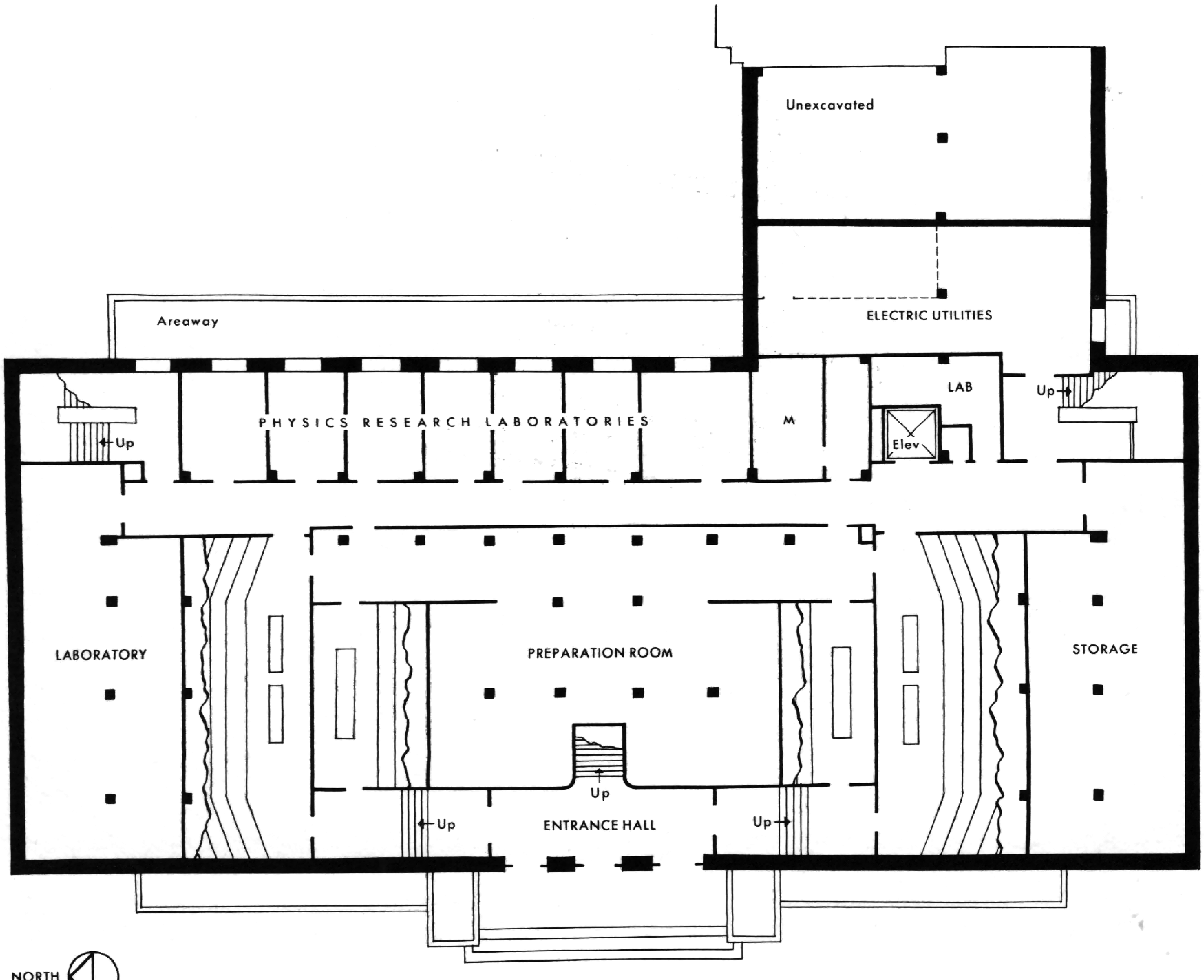
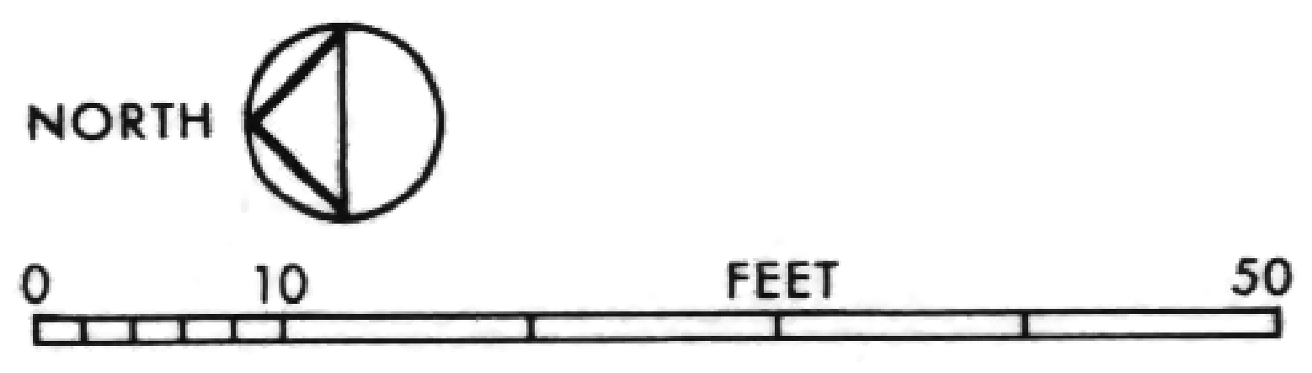
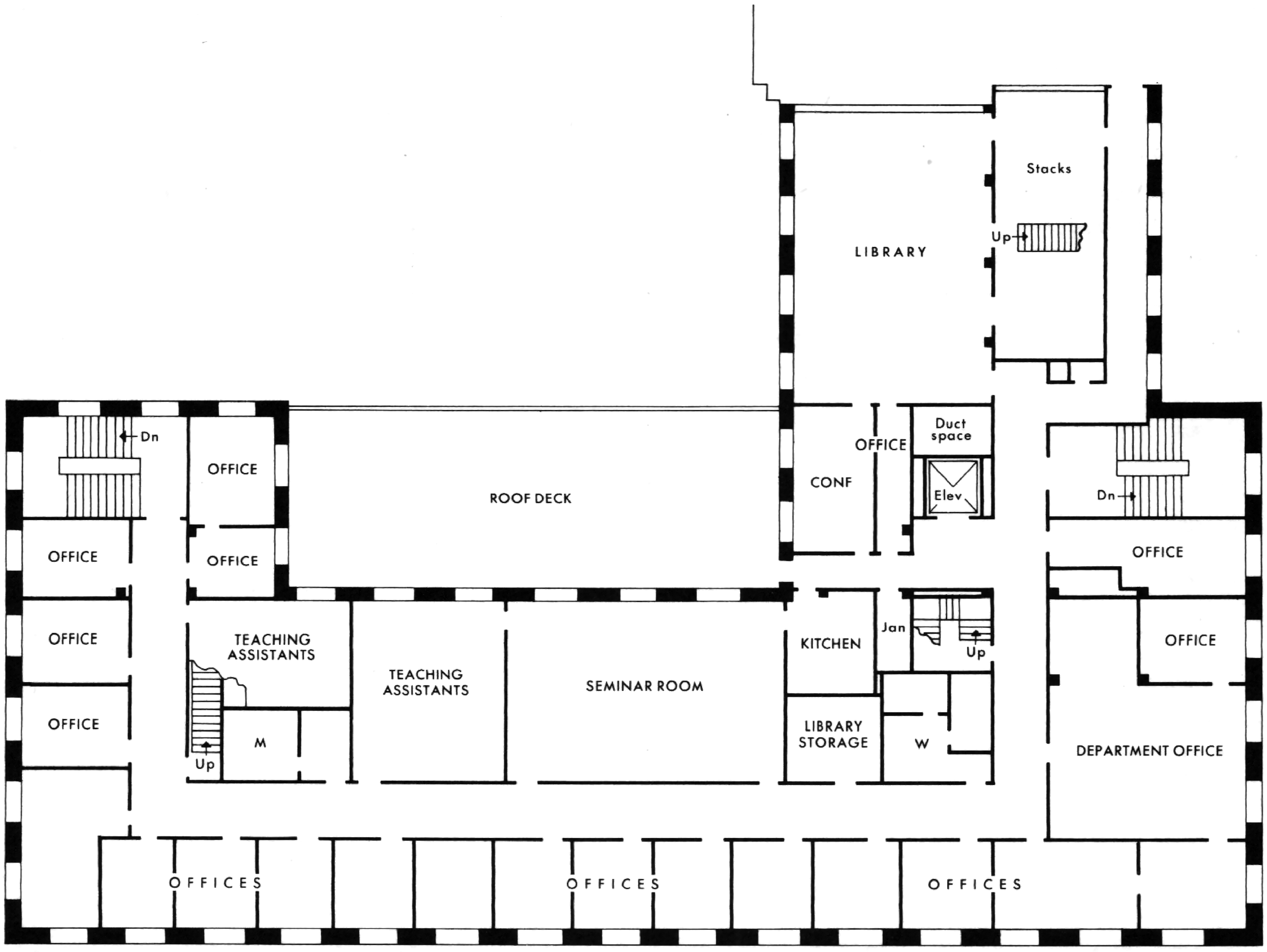
Dn
Up
Up
Dn
CHEM LAB
CHEM LAB
PHYSICS RESEARCH LABORATORIES
DARK ROOMS
DARK ROOM
W
Jan
Dn
LECTURE ROOM 4
203 seats
LECTURE ROOM 3
115 seats
LECTURE ROOM 2
102 seats
LECTURE ROOM 1
225 seats
VENTILATION EQUIPMENT

FIRST FLOOR PLAN

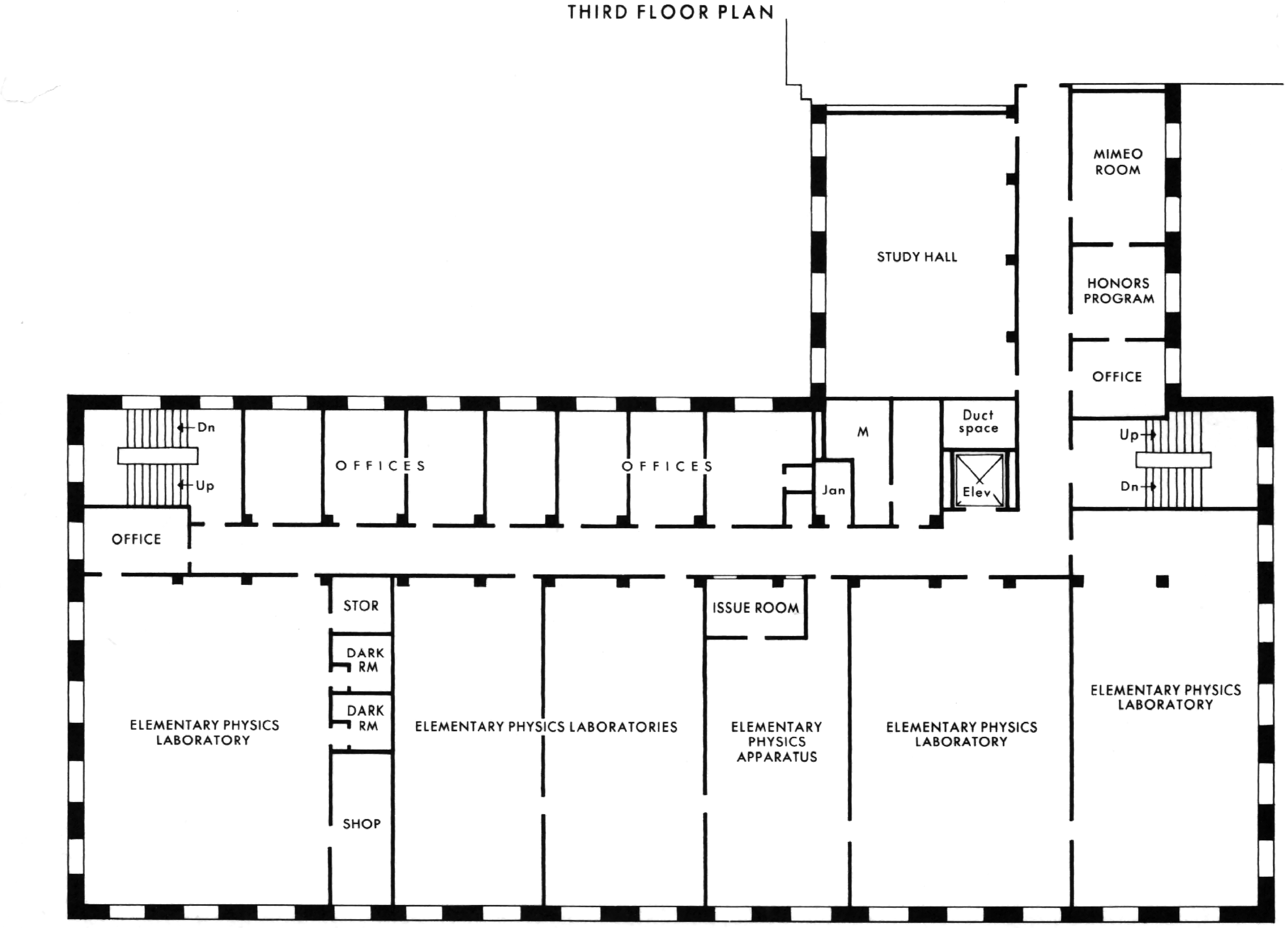

Unexcavated
Areaway
ELECTRIC UTILITIES
PHYSICS RESEARCH LABORATORIES
M
LAB
Elev
Up
Up
LABORATORY
PREPARATION ROOM
STORAGE
Up
Up
ENTRANCE HALL
Up


NORTH
0
10
FEET
50

BASEMENT PLAN


Stacks
Up
LIBRARY
Duct space
OFFICE
Dn
OFFICE
ROOF DECK
CONF
Elev
Dn
OFFICE
OFFICE
OFFICE
KITCHEN
Jan
Up
OFFICE
OFFICE
TEACHING ASSISTANTS
TEACHING ASSISTANTS
SEMINAR ROOM
OFFICE
M
Up
LIBRARY STORAGE
W
DEPARTMENT OFFICE
OFFICES
OFFICES
OFFICES

THIRD FLOOR PLAN


MIMEO ROOM
STUDY HALL
HONORS PROGRAM
OFFICE
Dn
Up
OFFICES
OFFICES
M
Duct space
Jan
Elev
Up
Dn
OFFICE
STOR
ISSUE ROOM
DARK RM
DARK RM
ELEMENTARY PHYSICS LABORATORY
ELEMENTARY PHYSICS LABORATORIES
ELEMENTARY PHYSICS APPARATUS
ELEMENTARY PHYSICS LABORATORY
ELEMENTARY PHYSICS LABORATORY
SHOP

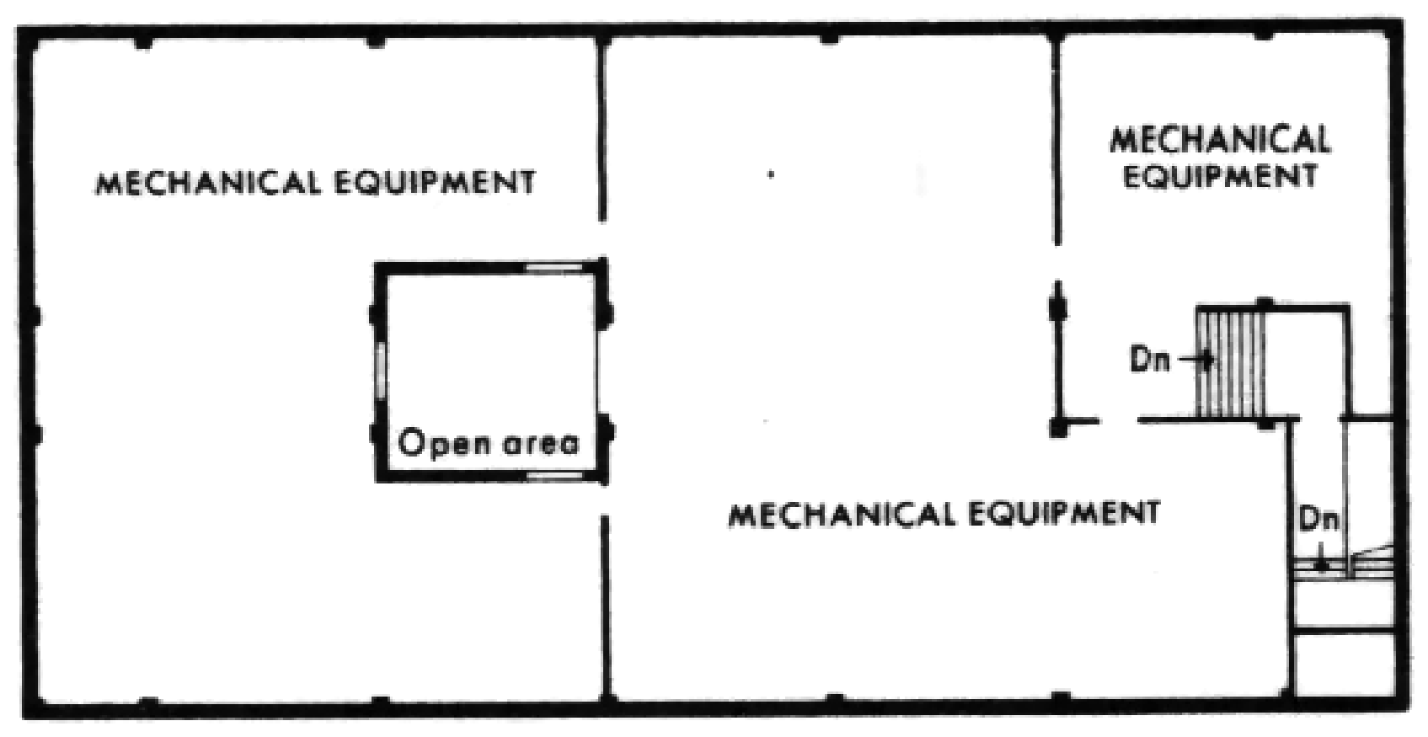
SECOND FLOOR PLAN

2.

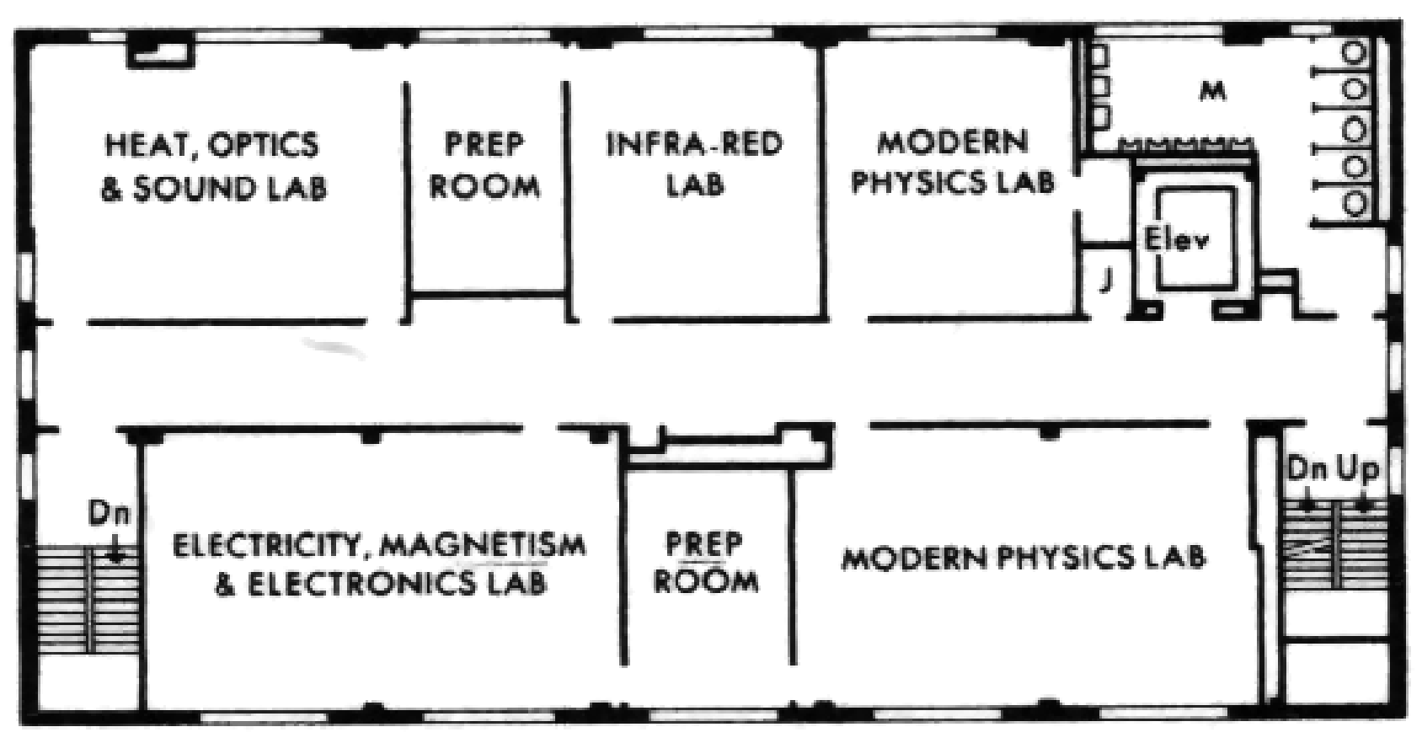
Keane Physics Research Center
The Catholic University of America
Washington, D. C.

Architects:	Murphy and Locraft Washington, D. C.
Completed:	July 1958
Gross Area of Building:	36,600 sq. ft.
Total Cost of Building:	$1,150,778*
Air Conditioning:	Yes

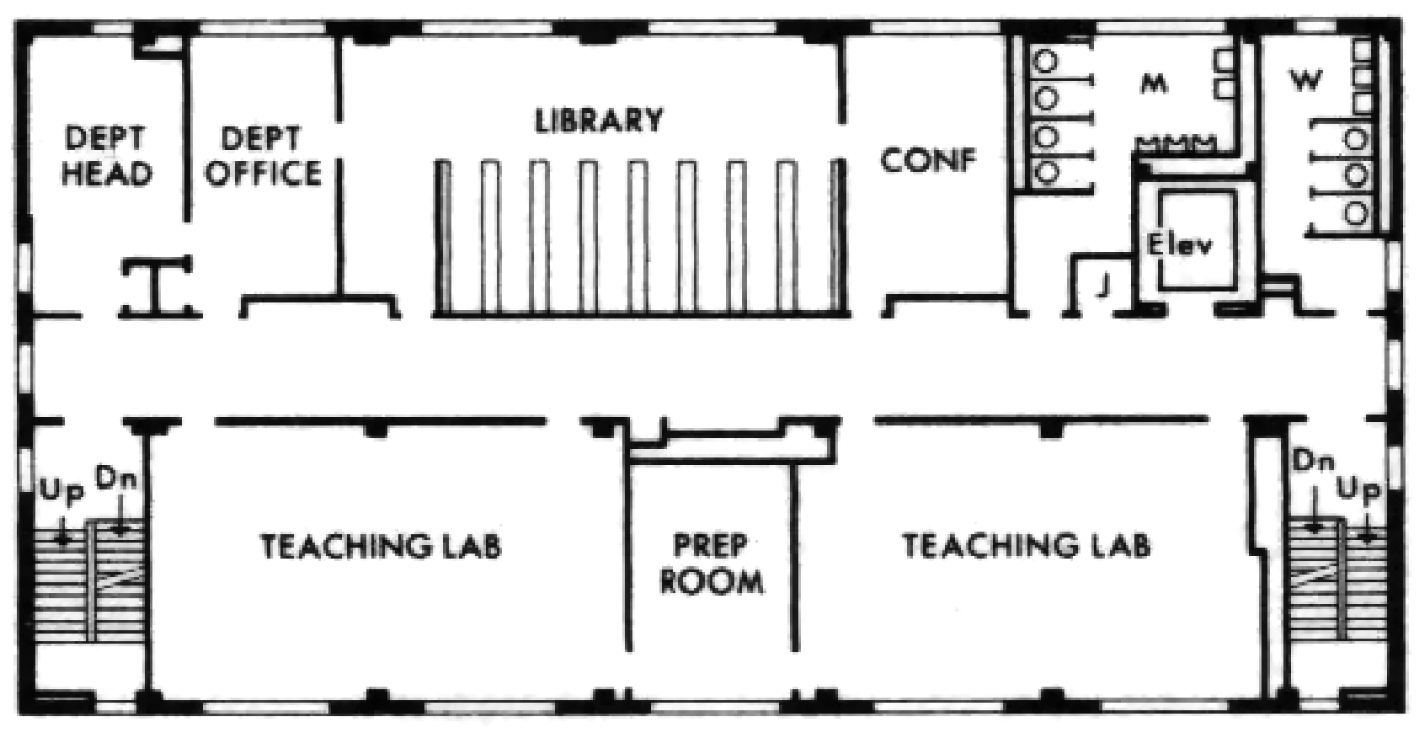
* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.


MECHANICAL EQUIPMENT
MECHANICAL EQUIPMENT
Open area
Dn
MECHANICAL EQUIPMENT
Dn

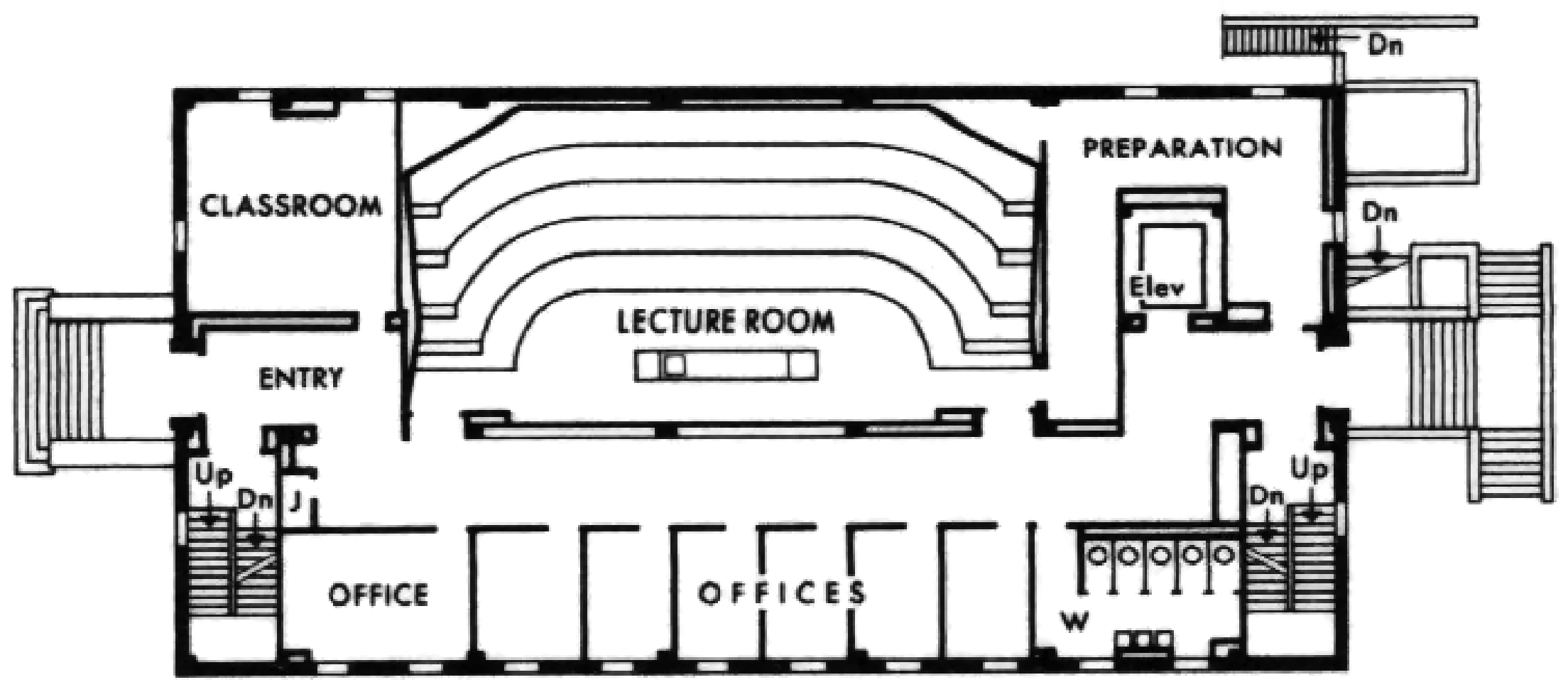
ATTIC FLOOR PLAN


HEAT, OPTICS & SOUND LAB
PREP ROOM
INFRA-RED LAB
MODERN PHYSICS LAB
M
Elev
J
Dn
ELECTRICITY, MAGNETISM & ELECTRONICS LAB
PREP ROOM
MODERN PHYSICS LAB
Dn Up

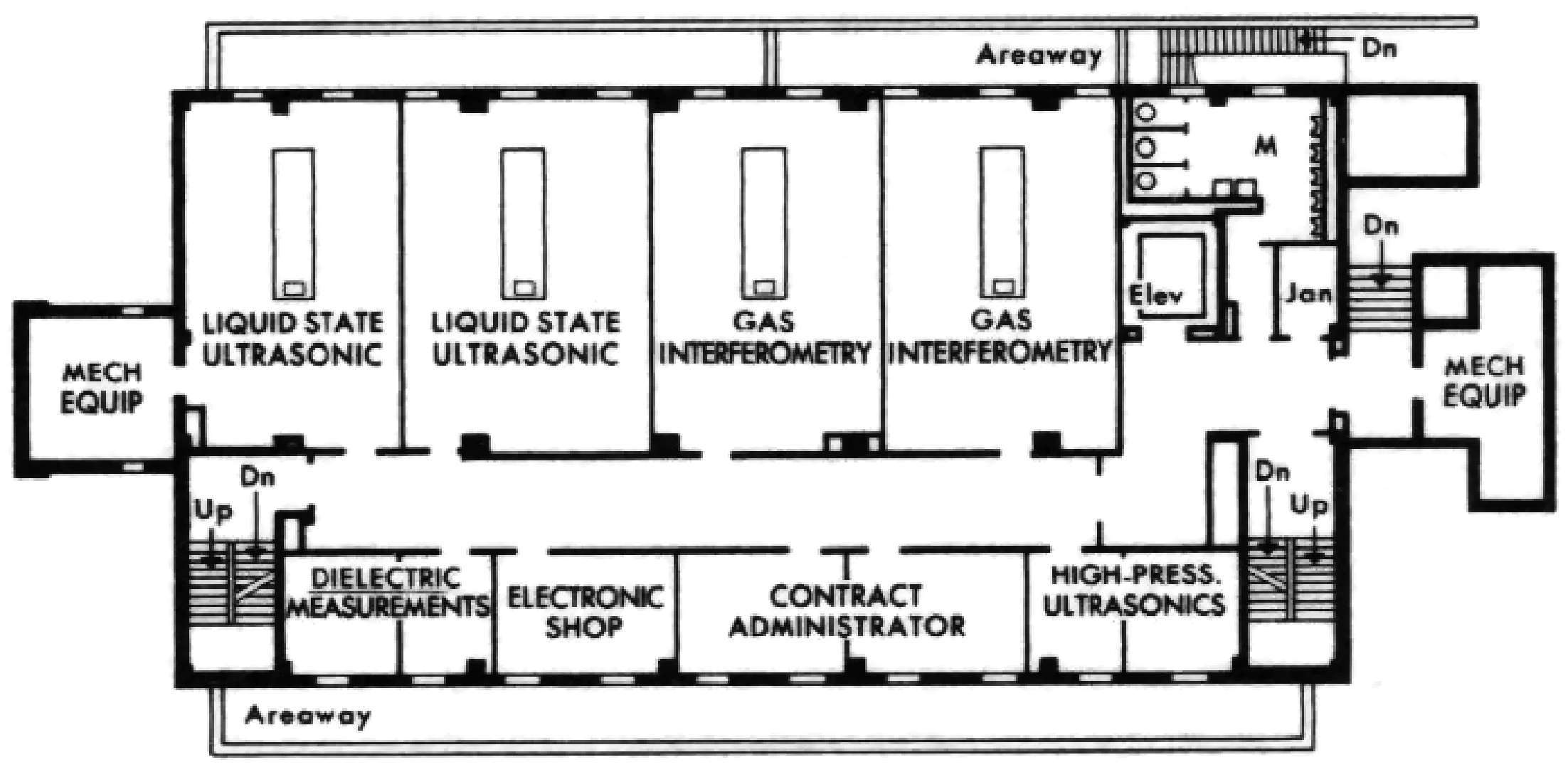
THIRD FLOOR PLAN


DEPT HEAD
DEPT OFFICE
LIBRARY
CONF
M
W
Elev
J
Up Dn
TEACHING LAB
PREP ROOM
TEACHING LAB
Dn Up

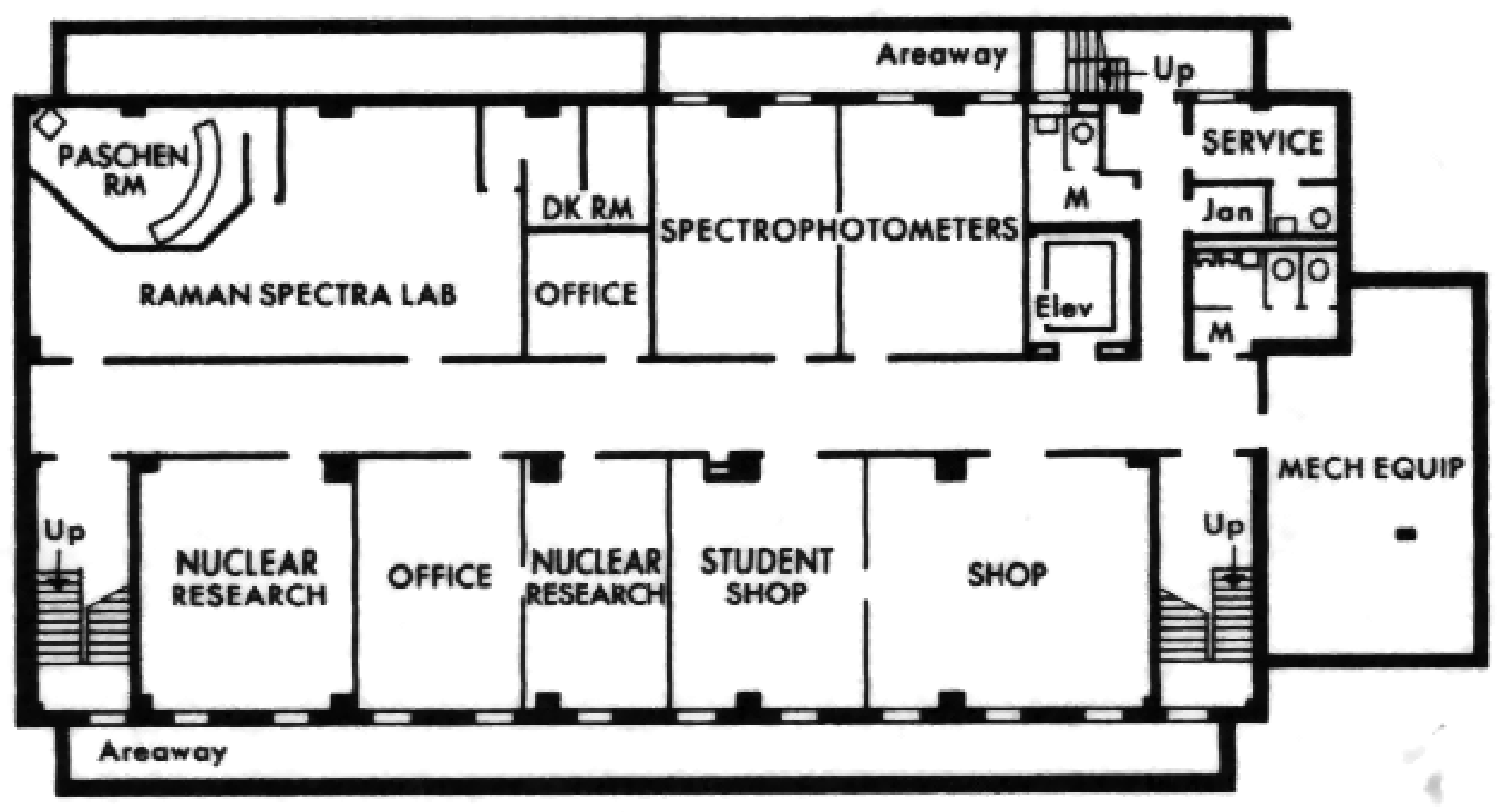
SECOND FLOOR PLAN


Dn
CLASSROOM
PREPARATION
Dn
LECTURE ROOM
Elev
ENTRY
Up
J
Dn
OFFICE
OFFICES
W
Up
Dn

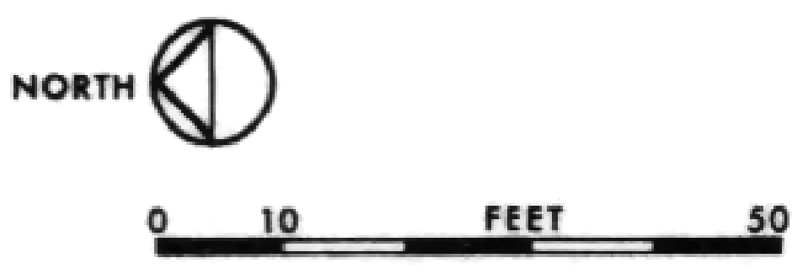
FIRST FLOOR PLAN


Areaway
Dn
M
Dn
MECH EQUIP
LIQUID STATE ULTRASONIC
LIQUID STATE ULTRASONIC
GAS INTERFEROMETRY
GAS INTERFEROMETRY
Elev
Jan
MECH EQUIP
Dn
Up
Dn
Up
DIELECTRIC MEASUREMENTS
ELECTRONIC SHOP
CONTRACT ADMINISTRATOR
HIGH-PRESS. ULTRASONICS
Areaway

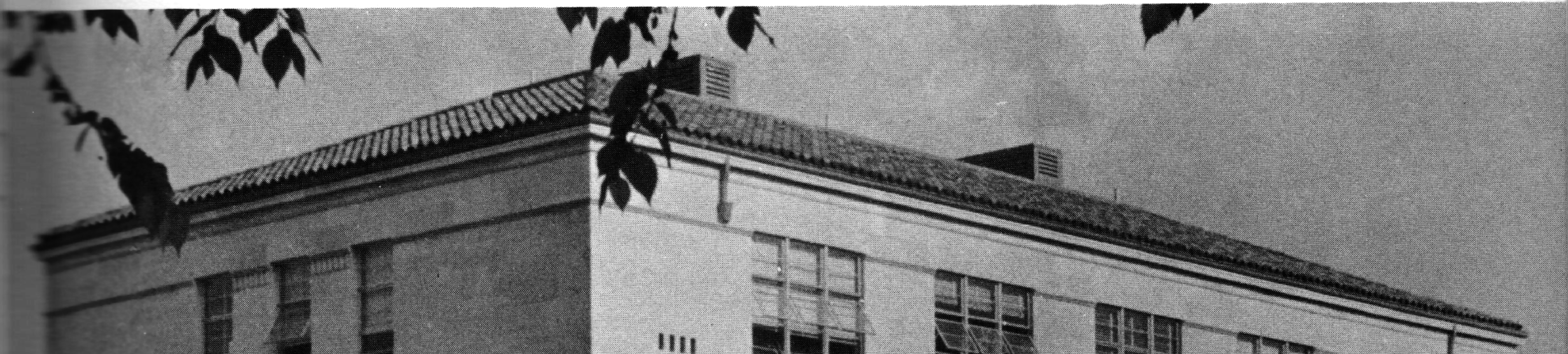
BASEMENT PLAN


Areaway
Up
PASCHEN RM
DK RM
SPECTROPHOTOMETERS
SERVICE
Jan
RAMAN SPECTRA LAB
OFFICE
Elev
M
MECH EQUIP
Up
NUCLEAR RESEARCH
OFFICE
NUCLEAR RESEARCH
STUDENT SHOP
SHOP
Up
Areaway

SUB-BASEMENT PLAN


NORTH
0
10
FEET
50

View of northwest corner, showing north entrance, one of two located at each end. Two floors below grade are open to areaways.

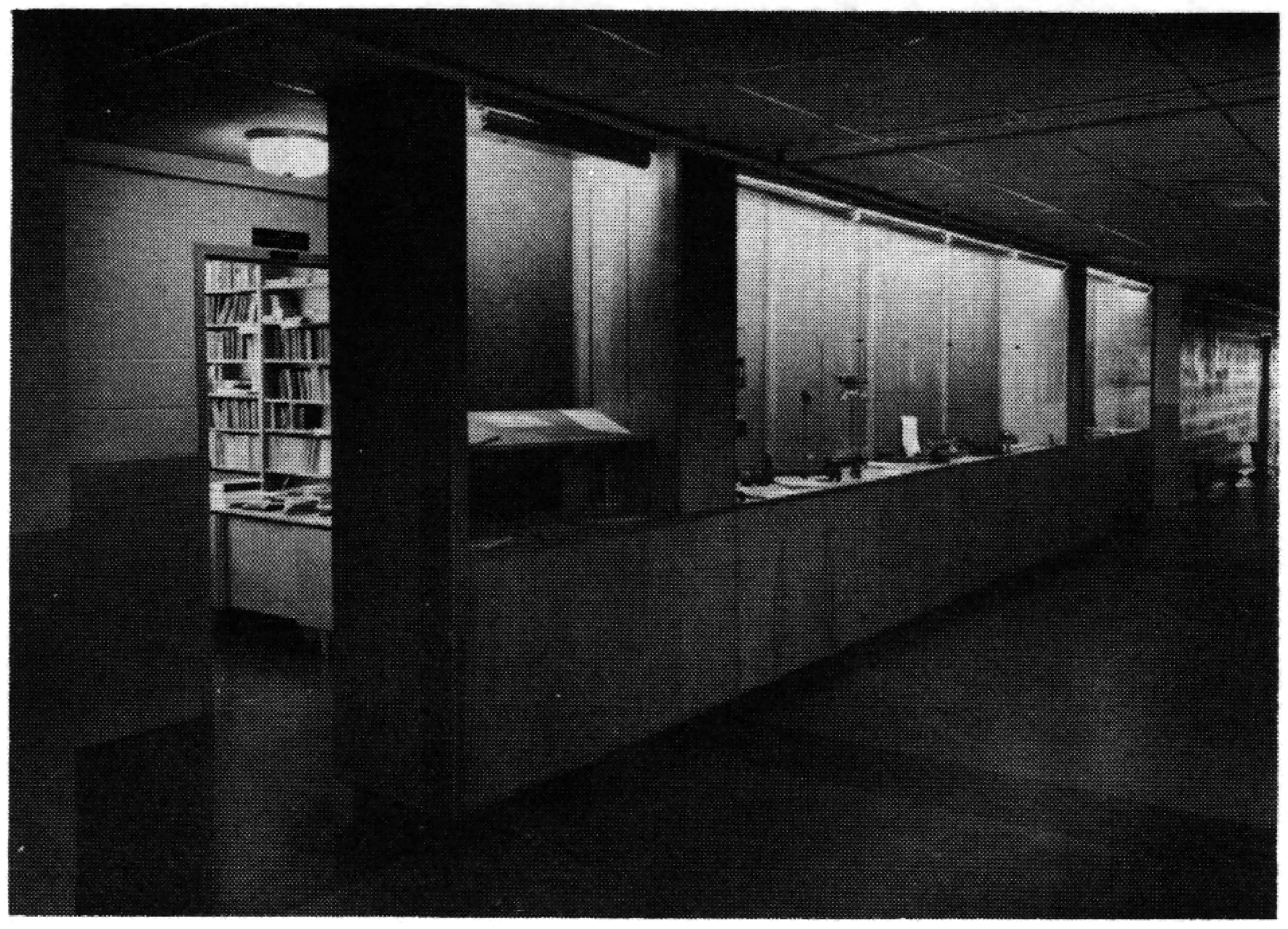


3.

Physics Building
University of Florida
Gainesville, Florida

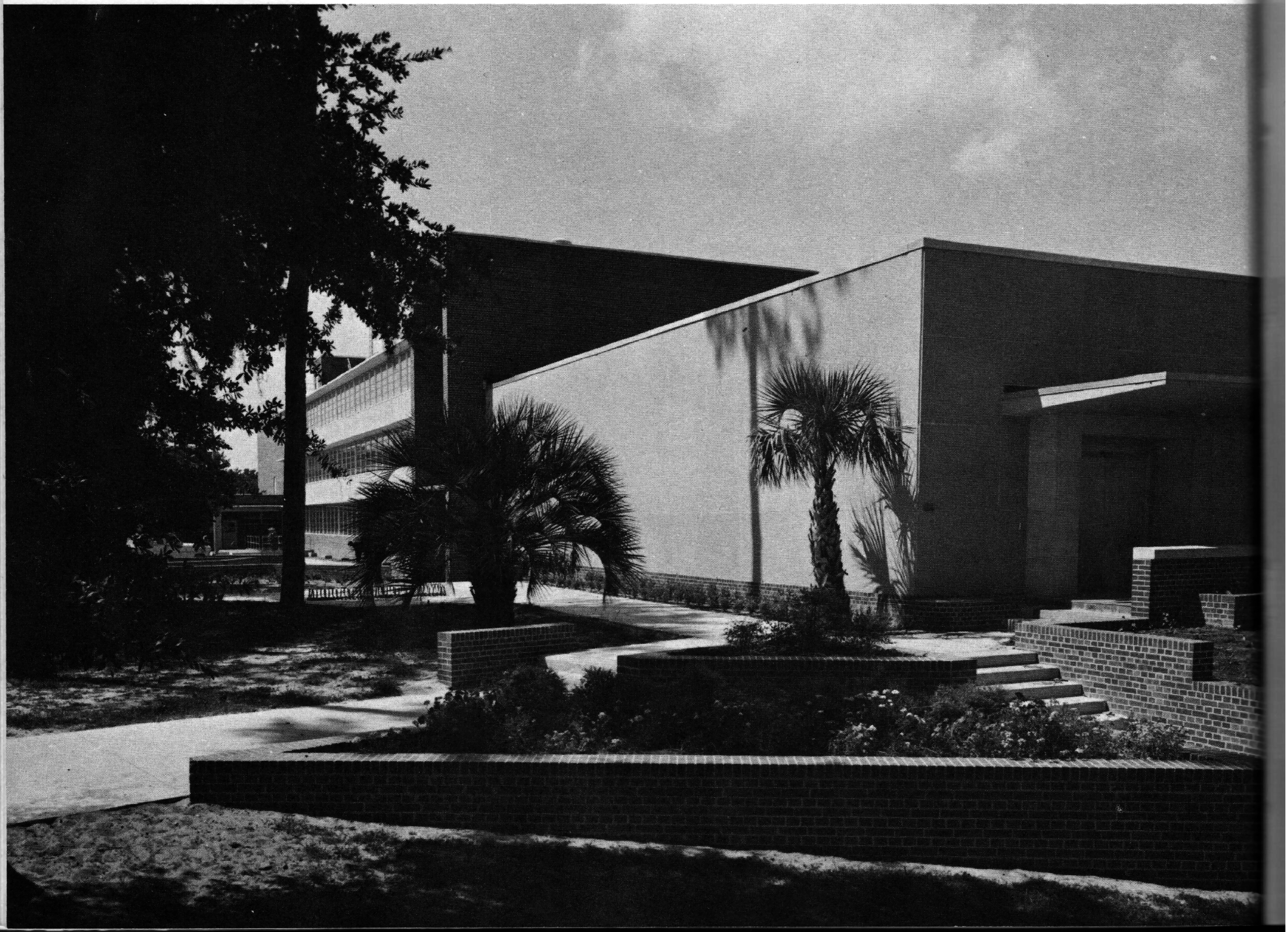
Architects:	Guy C. Fulton Gainesville, Florida
Completed:	April 1958
Gross Area of Building:	50,000 sq. ft.
Total Cost of Building:	$1,212,000*
Air Conditioning:	Carrier system

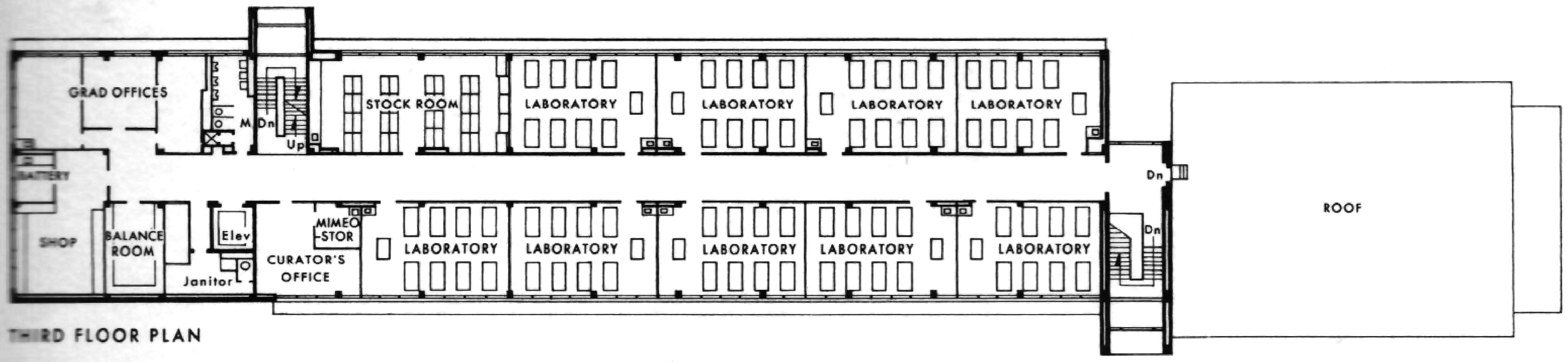
* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.



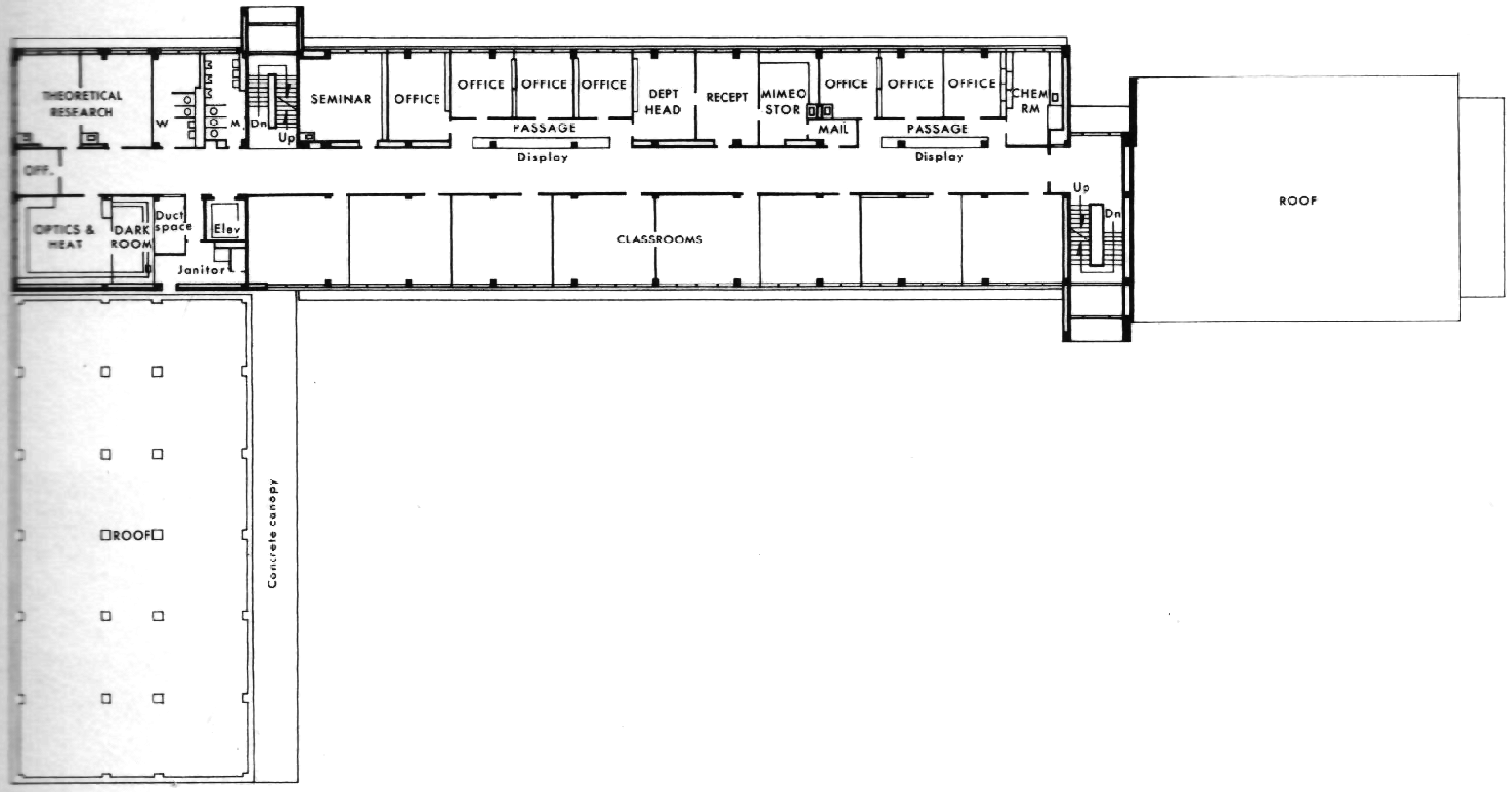
Display cases conceal secondary hall leading to offices.

Building viewed from lecture hall. Students enter hall directly from outside porch.

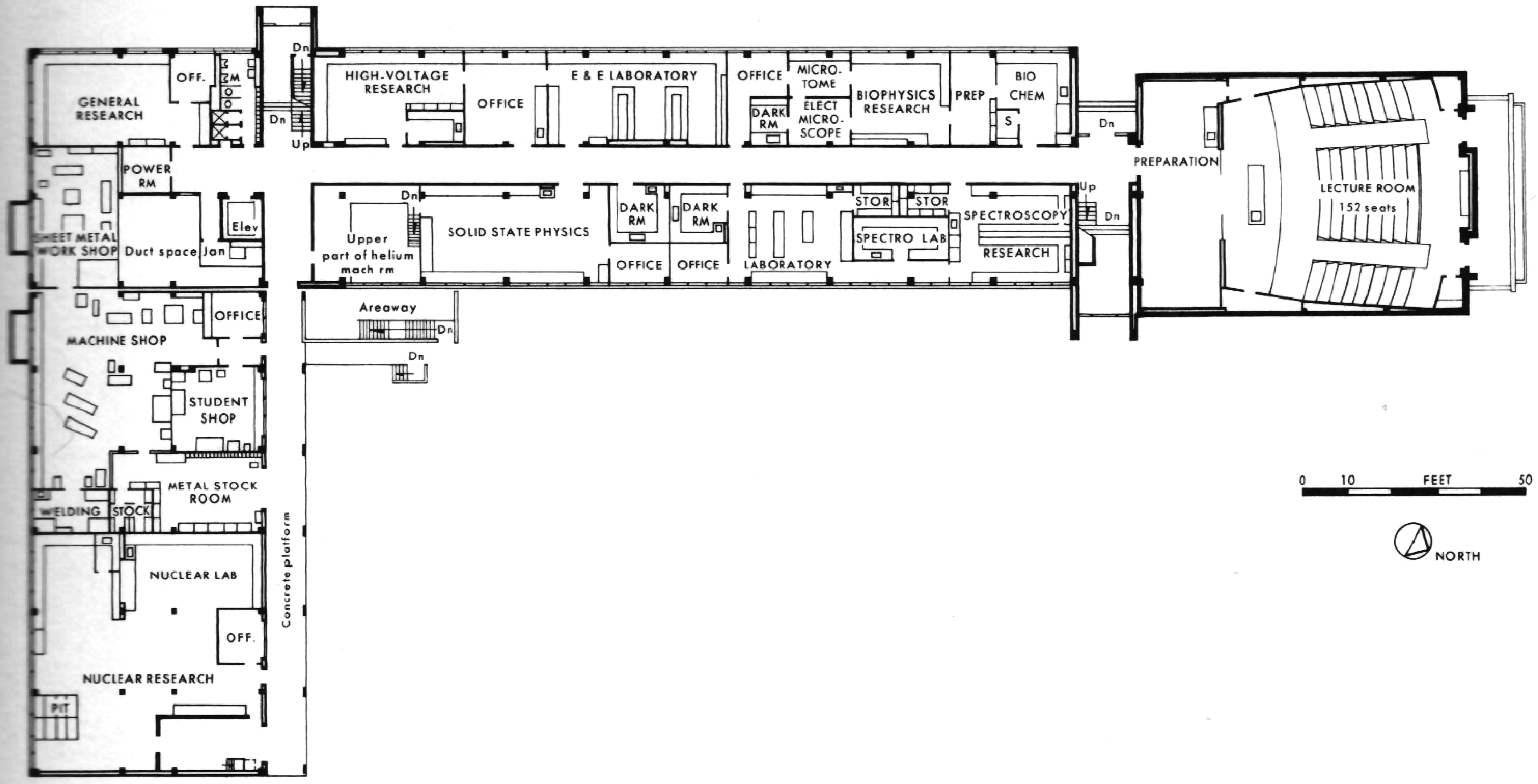



GRAD OFFICES
BATTERY
SHOP
BALANCE ROOM
Elev
Janitor
M
Dn
Up
MIMEO STOR
CURATOR'S OFFICE
STOCK ROOM
LABORATORY
LABORATORY
LABORATORY
LABORATORY
LABORATORY
LABORATORY
LABORATORY
LABORATORY
LABORATORY
Dn
Dn
ROOF

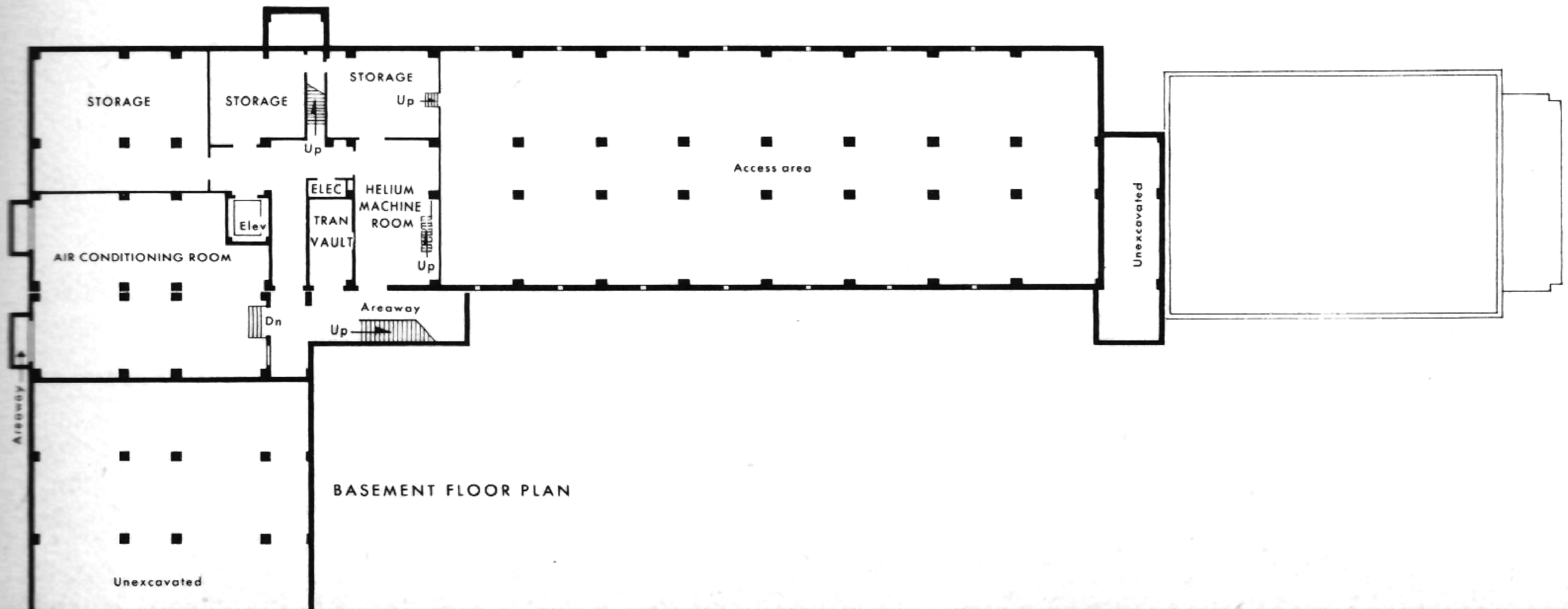
THIRD FLOOR PLAN


THEORETICAL RESEARCH
W
M
Dn
Up
OFF.
OPTICS & HEAT
DARK ROOM
Duct space
Elev
Janitor
SEMINAR
OFFICE
OFFICE
OFFICE
OFFICE
DEPT HEAD
RECEPT
MIMEO STOR
MAIL
OFFICE
OFFICE
OFFICE
CHEM RM
PASSAGE
Display
PASSAGE
Display
CLASSROOMS
Up
Dn
ROOF
ROOF
Concrete canopy

SECOND FLOOR PLAN


GENERAL RESEARCH
OFF.
M
Dn
Dn
Up
HIGH-VOLTAGE RESEARCH
OFFICE
E & E LABORATORY
OFFICE
MICRO-TOME
DARK RM
ELECT MICRO-SCOPE
BIOPHYSICS RESEARCH
PREP
BIO CHEM
S
Dn
POWER RM
SHEET METAL WORK SHOP
Duct space
Jan
Elev
Dn
Upper part of helium mach rm
SOLID STATE PHYSICS
DARK RM
DARK RM
OFFICE
OFFICE
LABORATORY
STOR
STOR
SPECTRO LAB
SPECTROSCOPY
RESEARCH
Up
Dn
PREPARATION
LECTURE ROOM
152 seats
OFFICE
MACHINE SHOP
Areaway
Dn
Dn
STUDENT SHOP
METAL STOCK ROOM
WELDING
STOCK
NUCLEAR LAB
OFF.
NUCLEAR RESEARCH
PIT
Concrete platform
0
10
FEET
50
NORTH

FIRST FLOOR PLAN


STORAGE
STORAGE
STORAGE
Up
Up
Access area
Elev
AIR CONDITIONING ROOM
ELEC
TRAN VAULT
HELIUM MACHINE ROOM
Up
Dn
Up
Areaway
Unexcavated
Areaway
Unexcavated

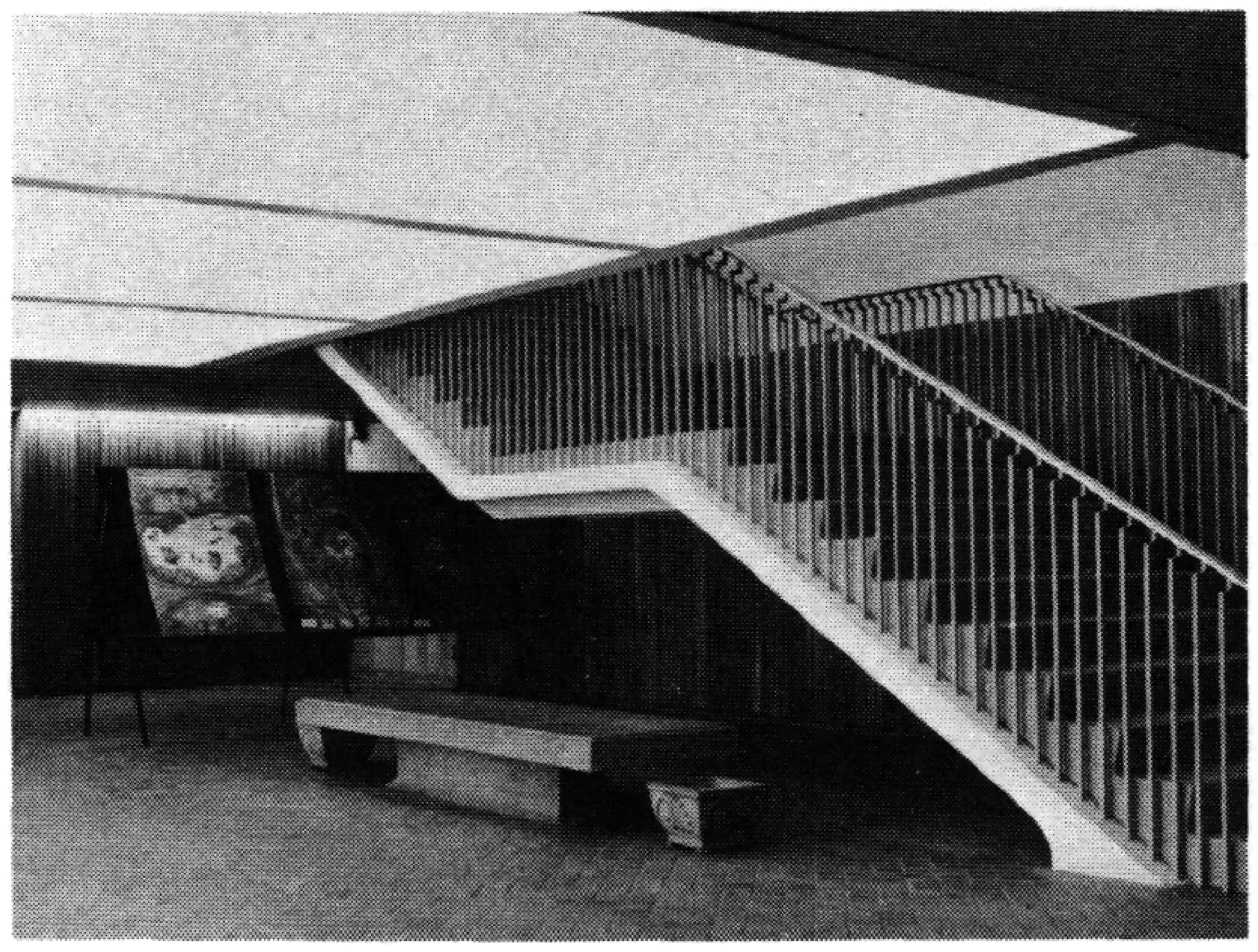
BASEMENT FLOOR PLAN

4.

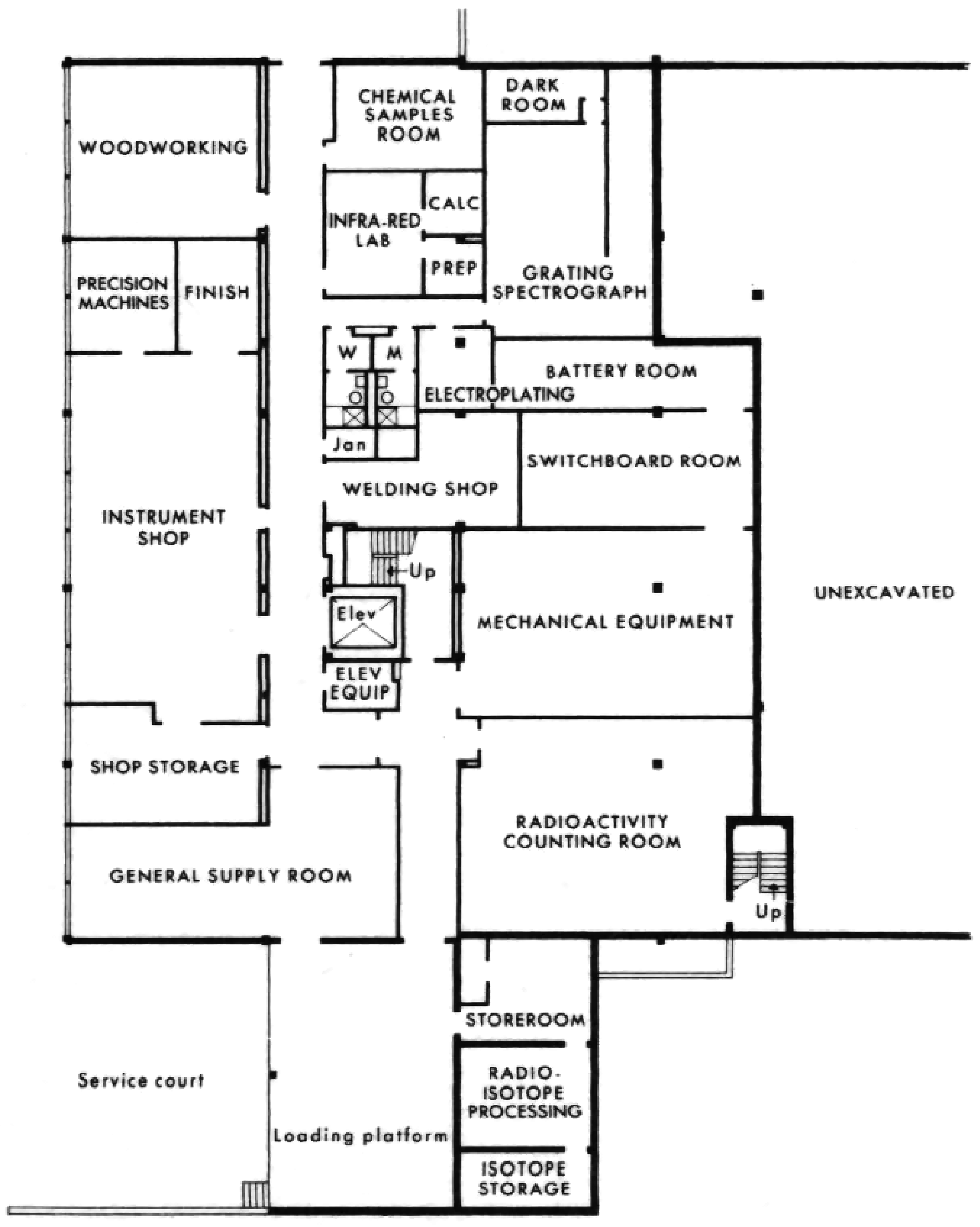
Physics Building
University of Georgia
Athens, Georgia

Architects:	Toombs, Amisano and Wells Atlanta, Georgia
Completed:	March 1959
Gross Area of Building:	67,000 sq. ft.
Total Cost of Building:	$1,750,000*
Air Conditioning:	York Refrigeration Machine—150 ton capacity. Cooling tower located on roof of building. 75% of the building is air conditioned.

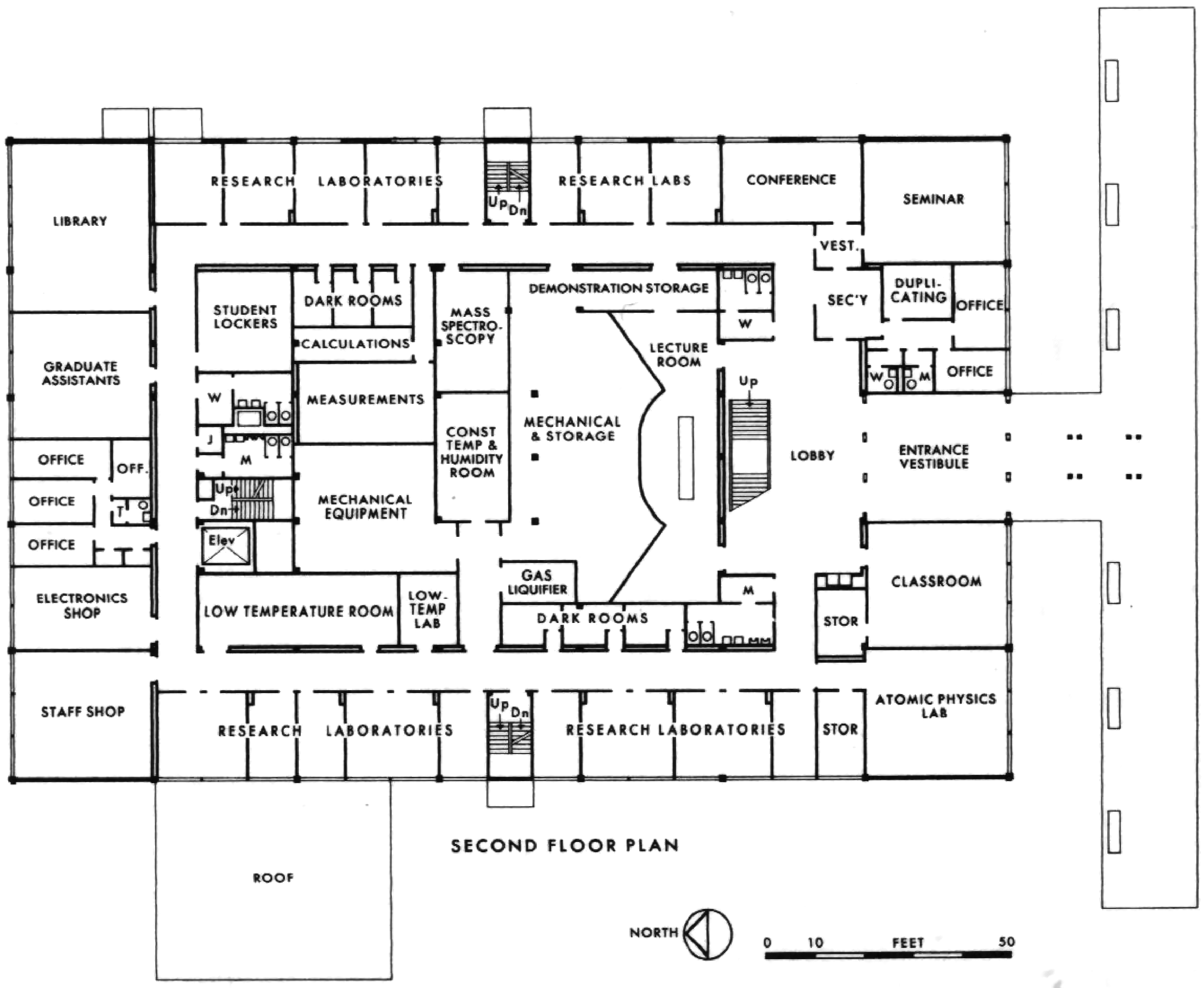
* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.



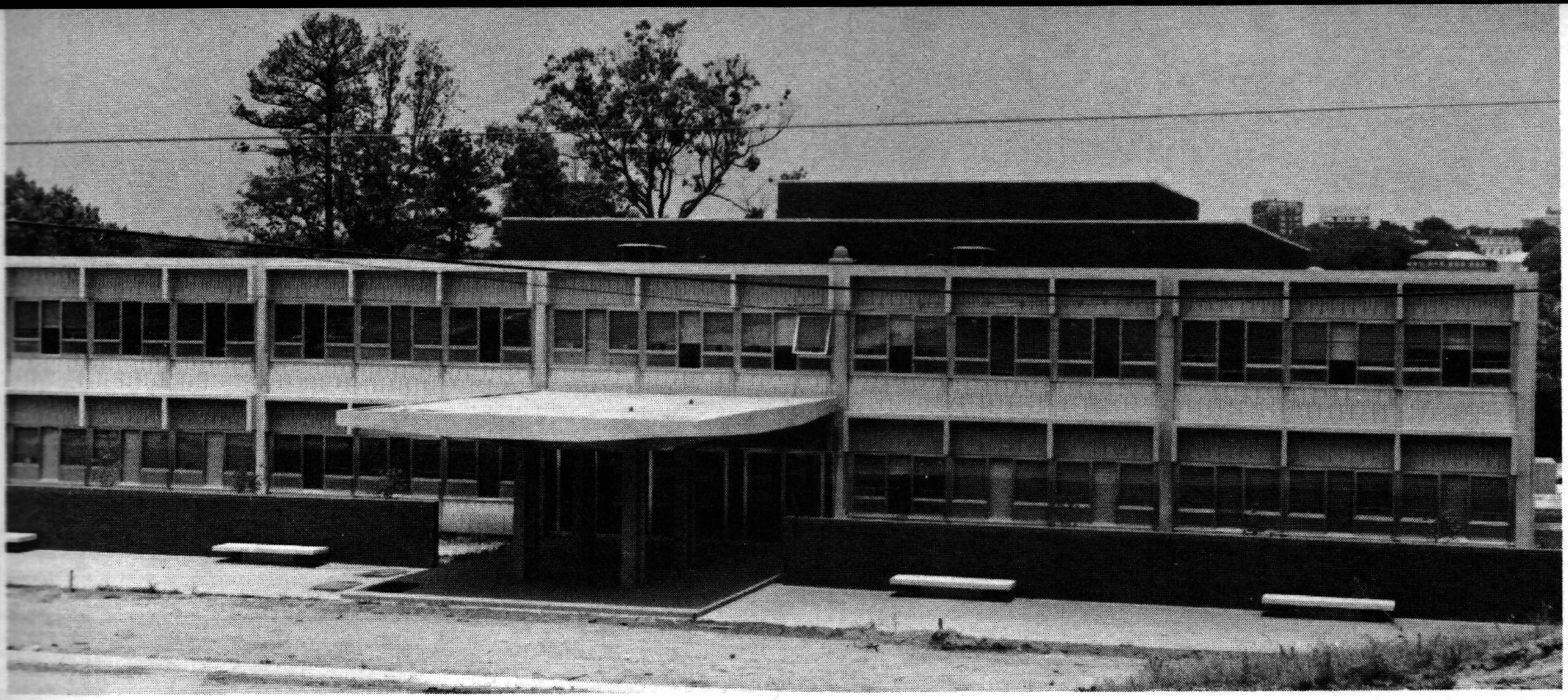
Stairs in entrance lobby are precast terrazzo; floor is brick.


CHEMICAL SAMPLES ROOM
DARK ROOM
WOODWORKING
CALC
INFRA-RED LAB
PREP
GRATING SPECTROGRAPH
PRECISION MACHINES
FINISH
W
M
BATTERY ROOM
ELECTROPLATING
Jan
SWITCHBOARD ROOM
WELDING SHOP
INSTRUMENT SHOP
Up
Elev
MECHANICAL EQUIPMENT
UNEXCAVATED
ELEV EQUIP
SHOP STORAGE
RADIOACTIVITY COUNTING ROOM
GENERAL SUPPLY ROOM
Up
STOREROOM
Service court
RADIO-ISOTOPE PROCESSING
Loading platform
ISOTOPE STORAGE

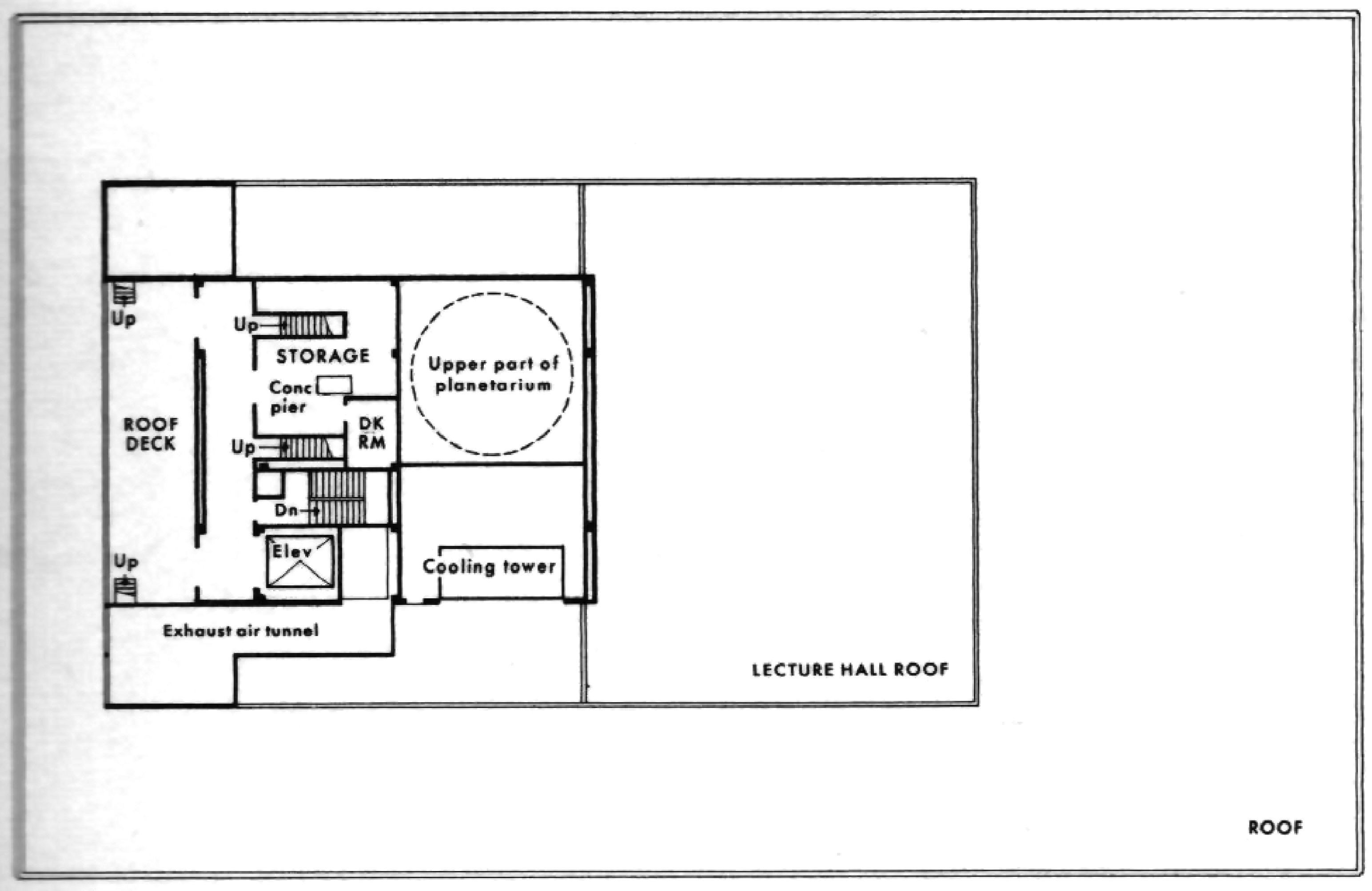
FIRST FLOOR PLAN


RESEARCH LABORATORIES
Up Dn
RESEARCH LABS
CONFERENCE
SEMINAR
LIBRARY
VEST.
STUDENT LOCKERS
DARK ROOMS
CALCULATIONS
MASS SPECTRO-SCOPY
DEMONSTRATION STORAGE
W
SEC'Y
DUPLI-CATING
OFFICE
GRADUATE ASSISTANTS
LECTURE ROOM
W
M
OFFICE
W
MEASUREMENTS
Up
J
M
CONST TEMP & HUMIDITY ROOM
MECHANICAL & STORAGE
LOBBY
ENTRANCE VESTIBULE
OFFICE
OFF.
OFFICE
T
Up
Dn
MECHANICAL EQUIPMENT
OFFICE
Elev
ELECTRONICS SHOP
LOW TEMPERATURE ROOM
LOW-TEMP LAB
GAS LIQUIFIER
DARK ROOMS
M
STOR
CLASSROOM
STAFF SHOP
RESEARCH LABORATORIES
Up Dn
RESEARCH LABORATORIES
STOR
ATOMIC PHYSICS LAB
ROOF
NORTH
0
10
FEET
50

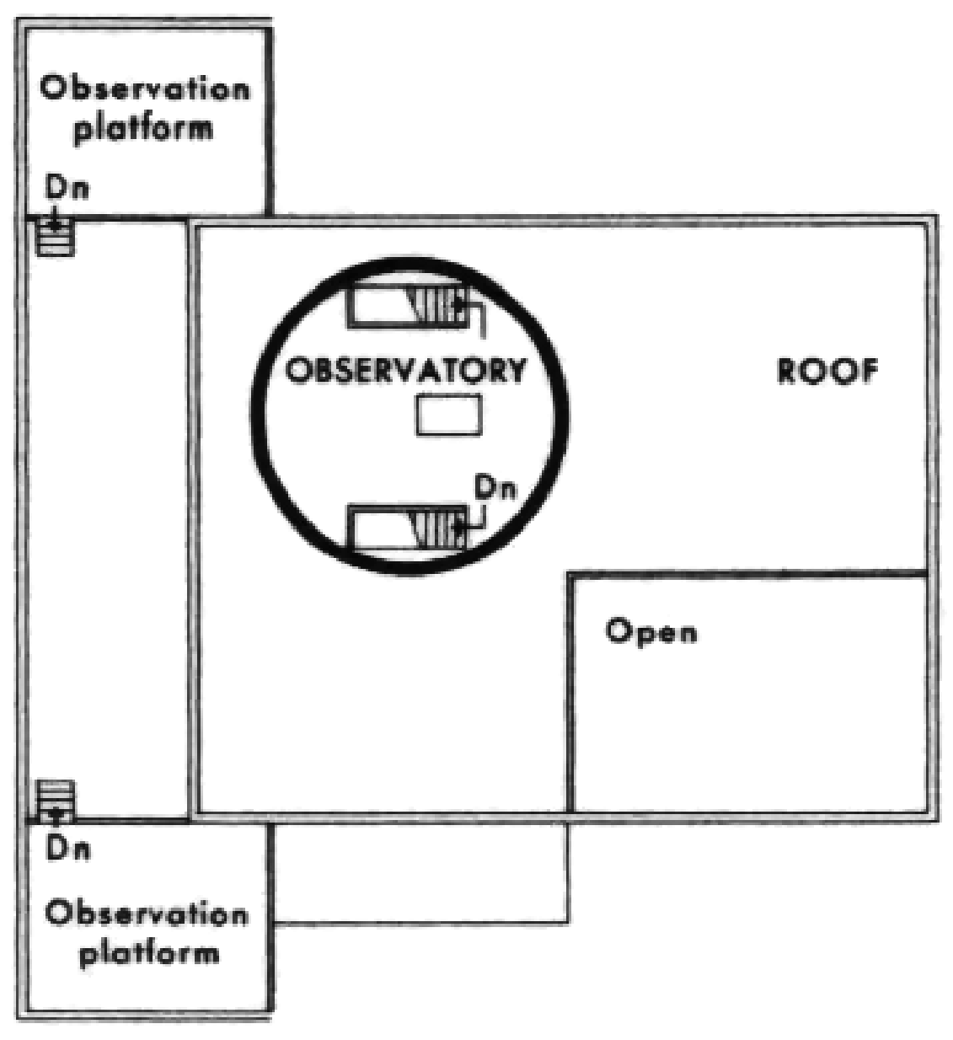
SECOND FLOOR PLAN



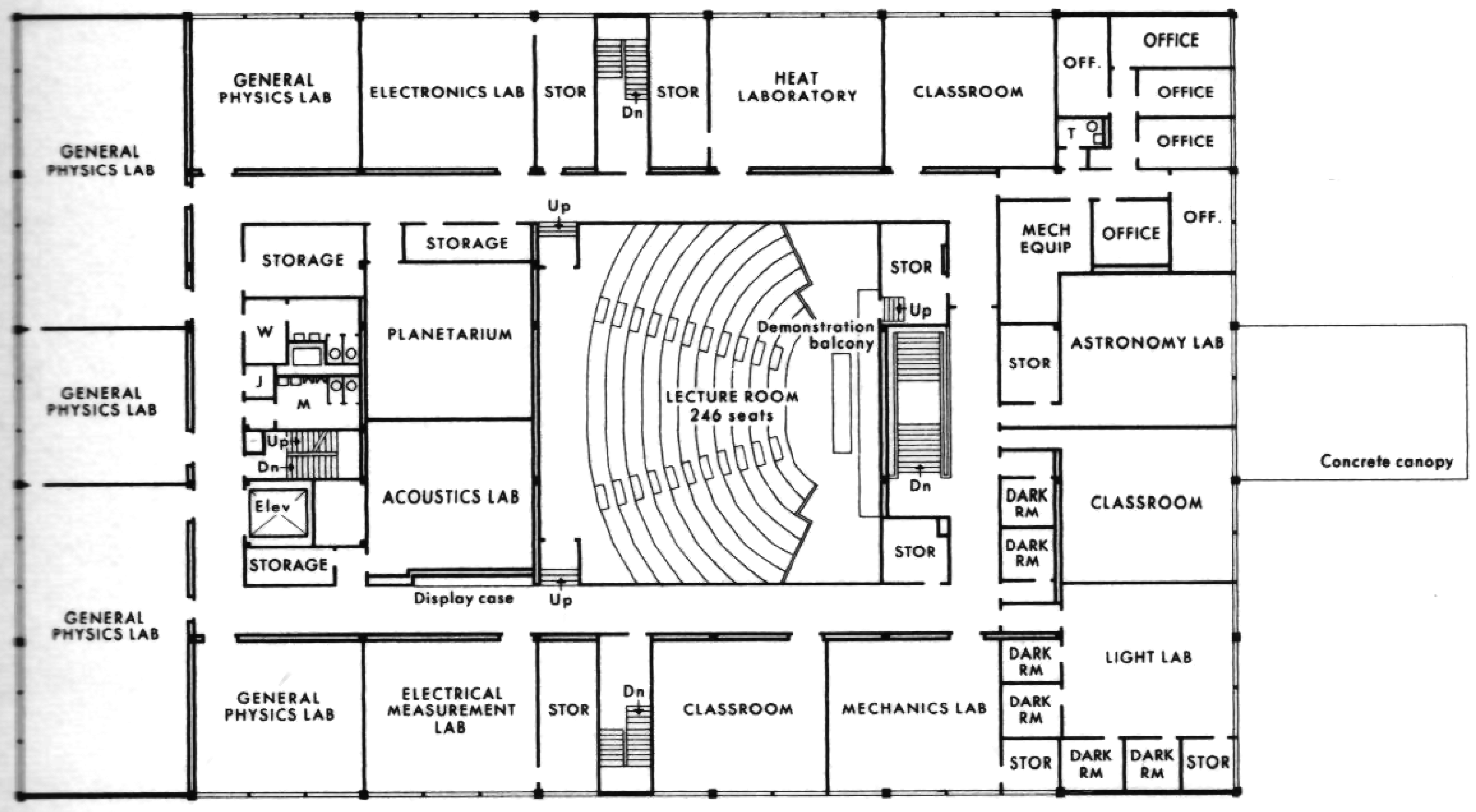
Principal elevation with entrance porch. Construction is concrete.


Up
Up
STORAGE
Conc pier
Upper part of planetarium
ROOF DECK
Up
DK RM
Dn
Elev
Cooling tower
Up
Exhaust air tunnel
LECTURE HALL ROOF
ROOF

FOURTH (PENTHOUSE) FLOOR PLAN


Observation platform
Dn
OBSERVATORY
Dn
ROOF
Open
Dn
Observation platform

ROOF (OBSERVATORY) PLAN


GENERAL PHYSICS LAB
ELECTRONICS LAB
STOR
Dn
STOR
HEAT LABORATORY
CLASSROOM
OFF.
OFFICE
OFFICE
OFFICE
T
GENERAL PHYSICS LAB
Up
MECH EQUIP
OFFICE
OFF.
STORAGE
STORAGE
STOR
Up
Demonstration balcony
W
PLANETARIUM
ASTRONOMY LAB
J
M
LECTURE ROOM 246 seats
STOR
GENERAL PHYSICS LAB
Up
Dn
Dn
Concrete canopy
Elev
ACOUSTICS LAB
DARK RM
CLASSROOM
DARK RM
STORAGE
STOR
Display case
Up
GENERAL PHYSICS LAB
DARK RM
LIGHT LAB
GENERAL PHYSICS LAB
ELECTRICAL MEASUREMENT LAB
STOR
Dn
CLASSROOM
MECHANICS LAB
DARK RM
STOR
DARK RM
DARK RM
STOR

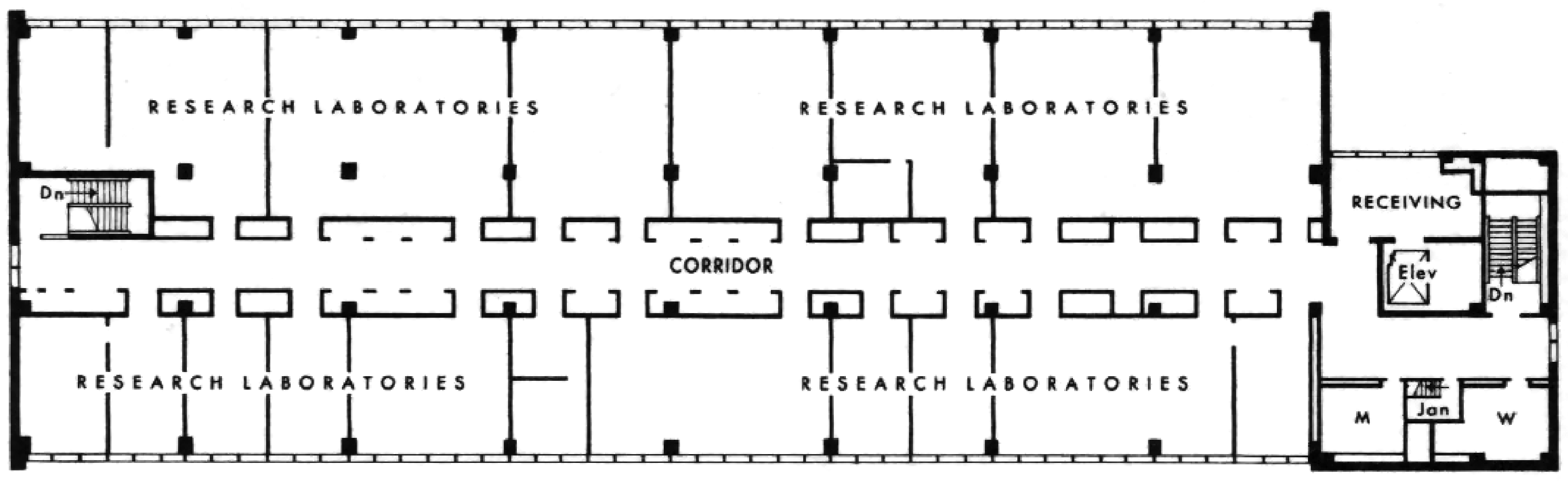
THIRD FLOOR PLAN

5.

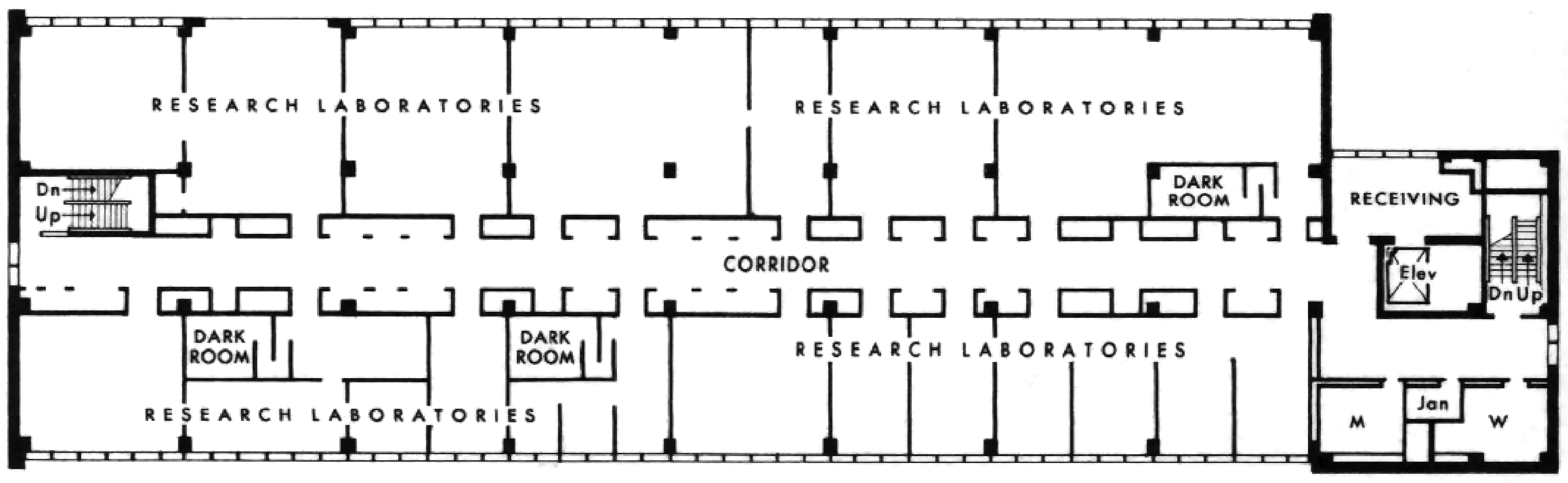
Gordon McKay Laboratory of Applied Science
Harvard University
Cambridge, Massachusetts

Architects:	Shepley, Bulfinch, Richardson and Abbott Boston, Massachusetts
Completed:	1953
Gross Area of Building:	54,080 sq. ft.
Total Cost of Building:	$850,000*
Air Conditioning:	None

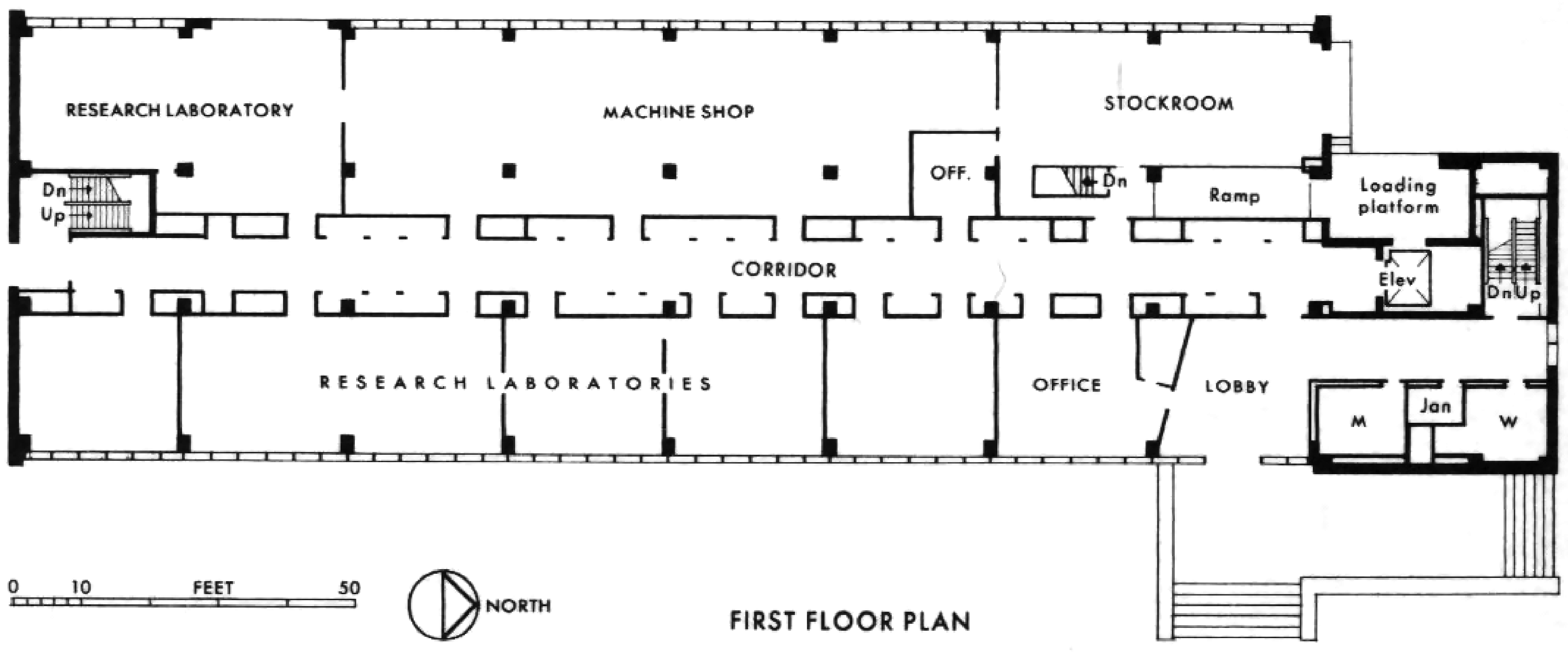
* Includes heating, ventilating, electrical and mechanical services. Does not include laboratory furniture.


RESEARCH LABORATORIES
RESEARCH LABORATORIES
Dn
CORRIDOR
RECEIVING
Elev
Dn
RESEARCH LABORATORIES
RESEARCH LABORATORIES
M
Jan
W

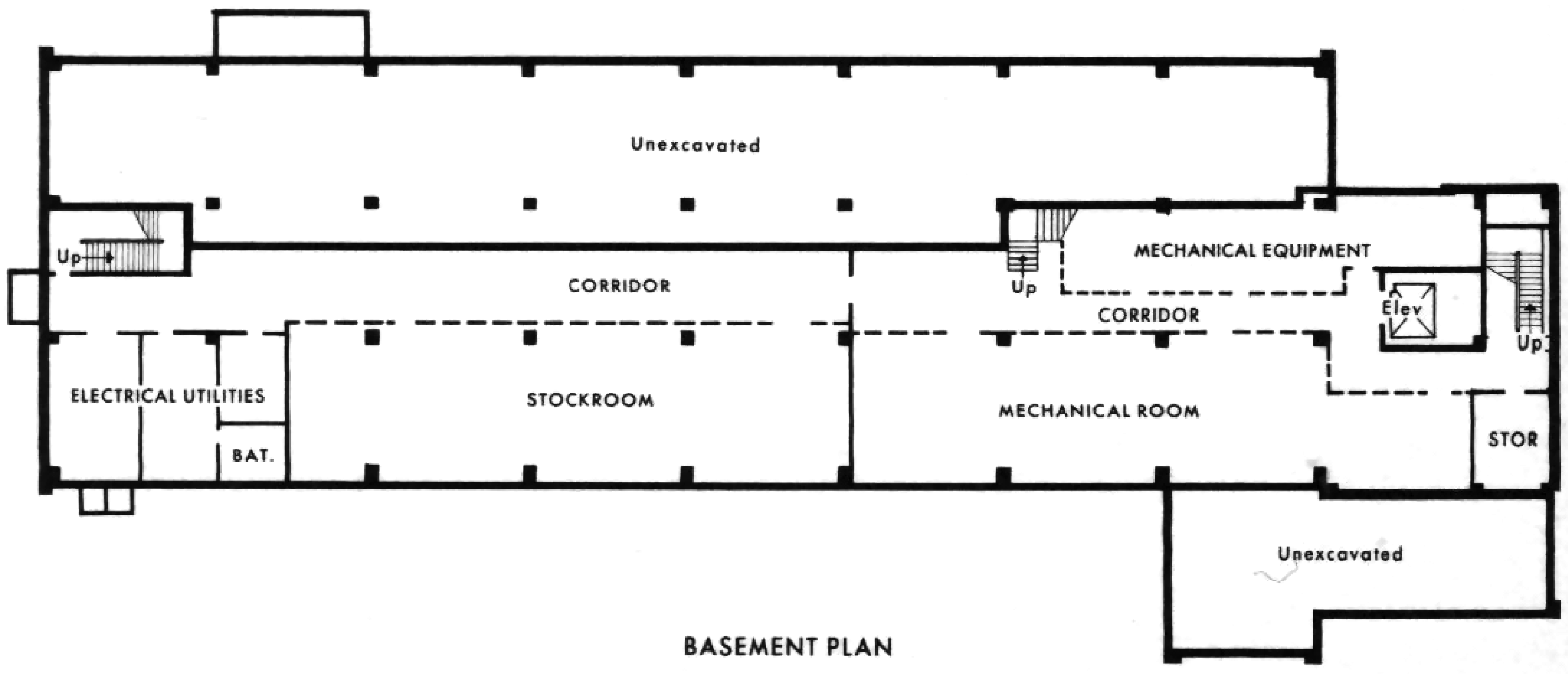
THIRD FLOOR PLAN


RESEARCH LABORATORIES
RESEARCH LABORATORIES
DARK ROOM
RECEIVING
Dn
Up
CORRIDOR
Elev
Dn Up
DARK ROOM
DARK ROOM
RESEARCH LABORATORIES
RESEARCH LABORATORIES
M
Jan
W

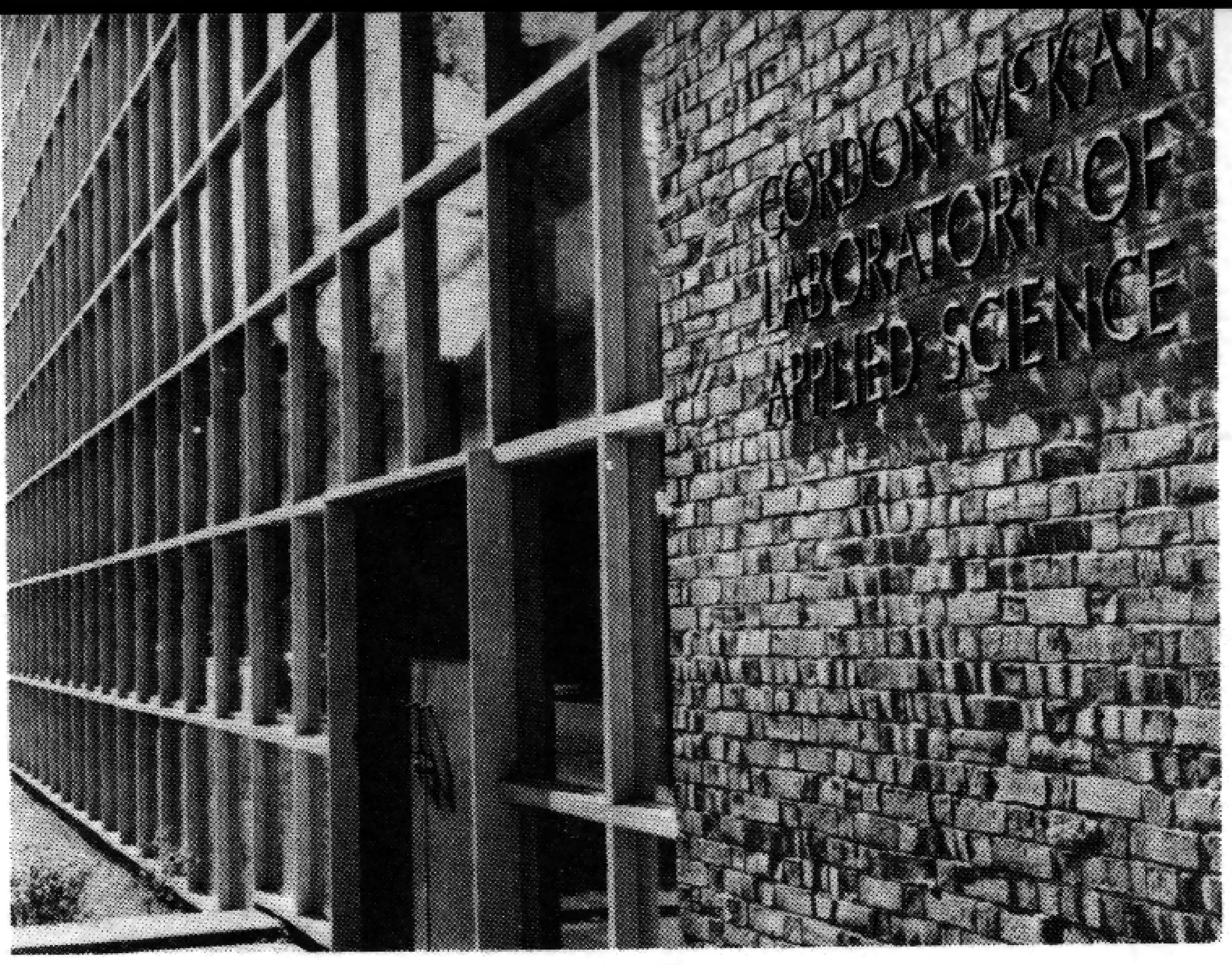
SECOND FLOOR PLAN


RESEARCH LABORATORY
MACHINE SHOP
STOCKROOM
OFF.
Dn
Ramp
Loading platform
Dn
Up
CORRIDOR
Elev
Dn Up
RESEARCH LABORATORIES
OFFICE
LOBBY
M
Jan
W
0
10
FEET
50
NORTH

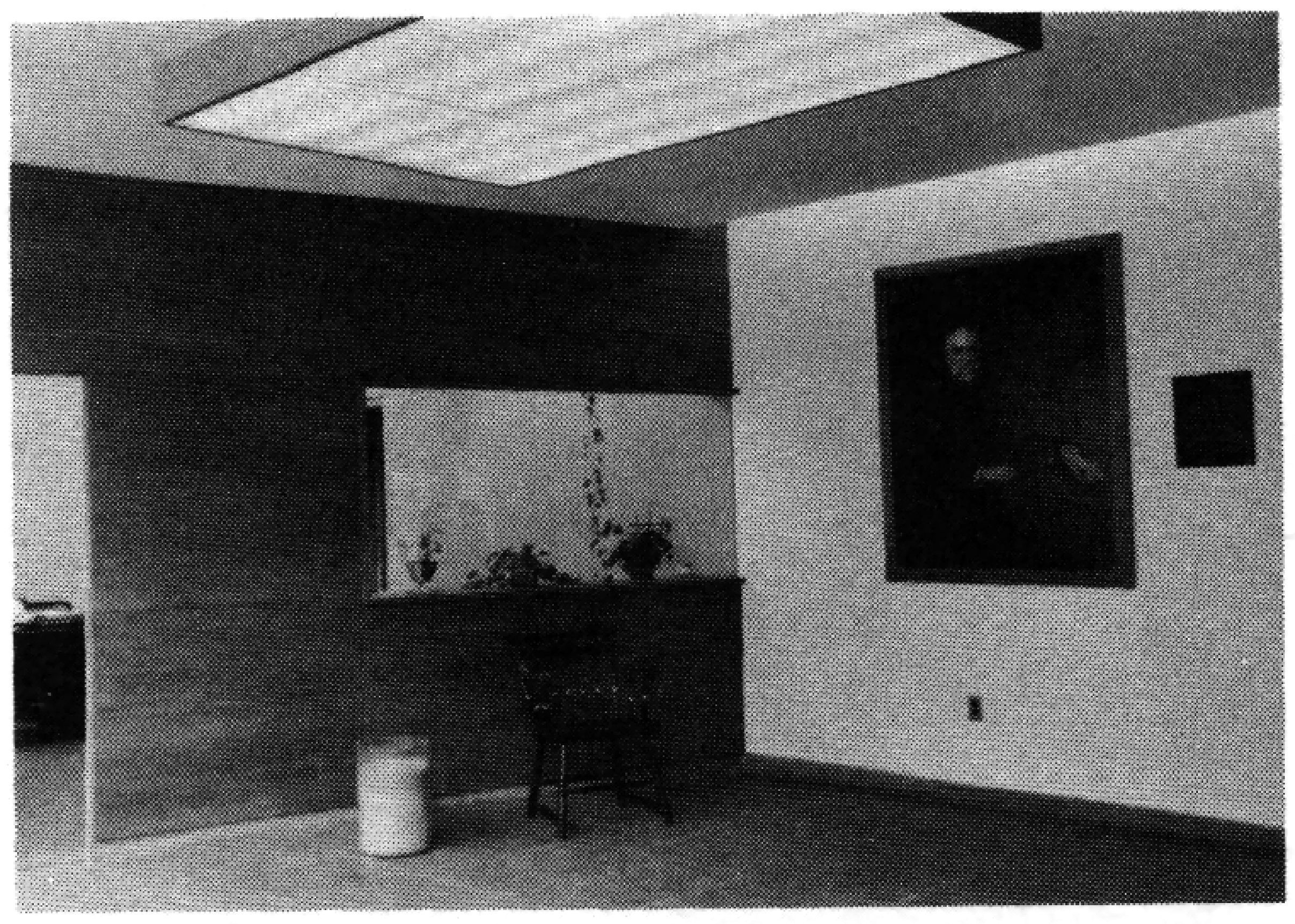
FIRST FLOOR PLAN


Unexcavated
Up
CORRIDOR
Up
MECHANICAL EQUIPMENT
CORRIDOR
Elev
Up
ELECTRICAL UTILITIES
BAT.
STOCKROOM
MECHANICAL ROOM
STOR
Unexcavated

BASEMENT PLAN

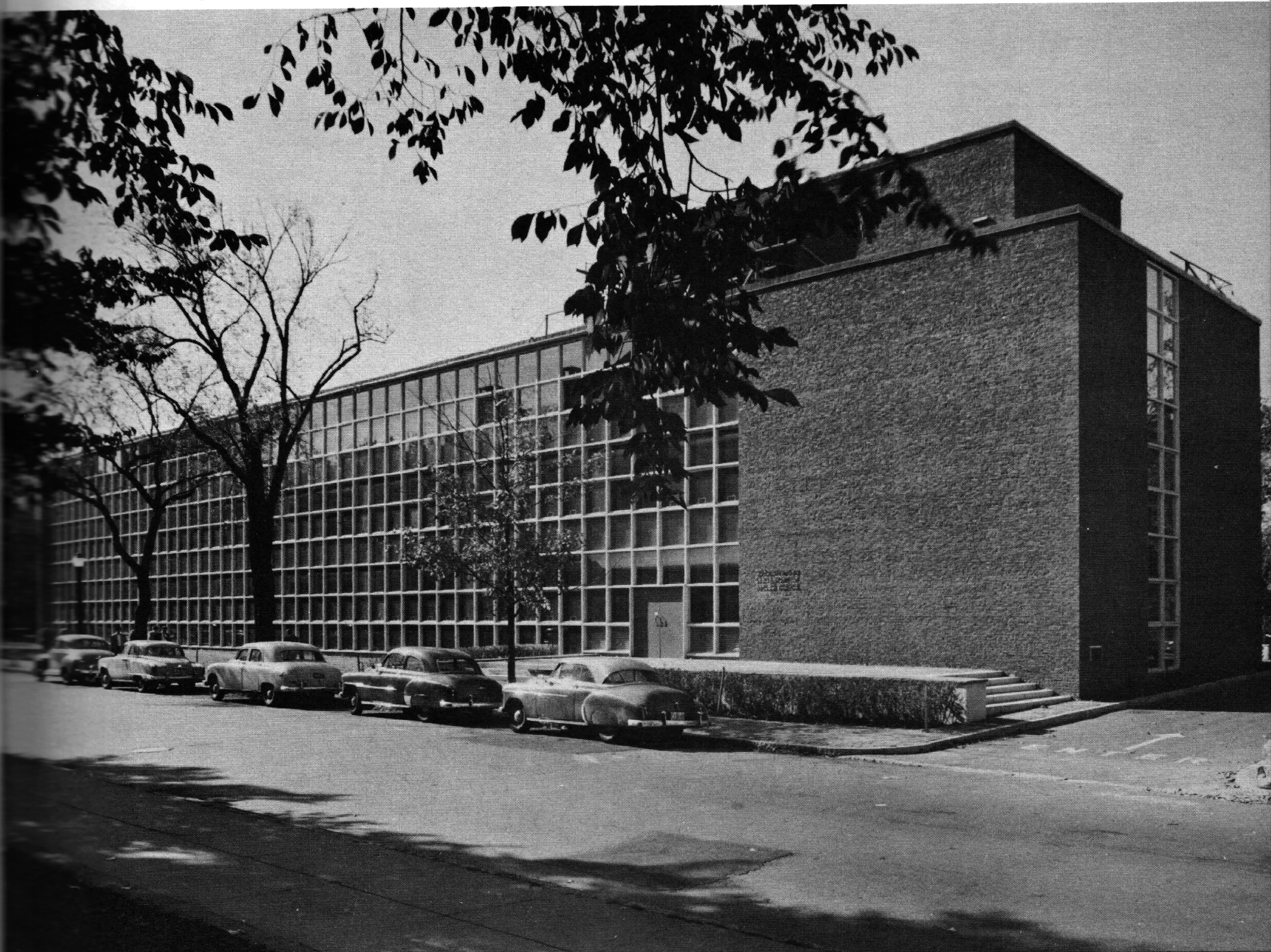

GORDON McKAY
LABORATORY OF
APPLIED SCIENCE

Entrance detail showing redwood grid framing for doors, sash, and paneling.



View of lobby showing reception area.

Street elevation. (Entrance drive to receiving and parking area is in rear.)



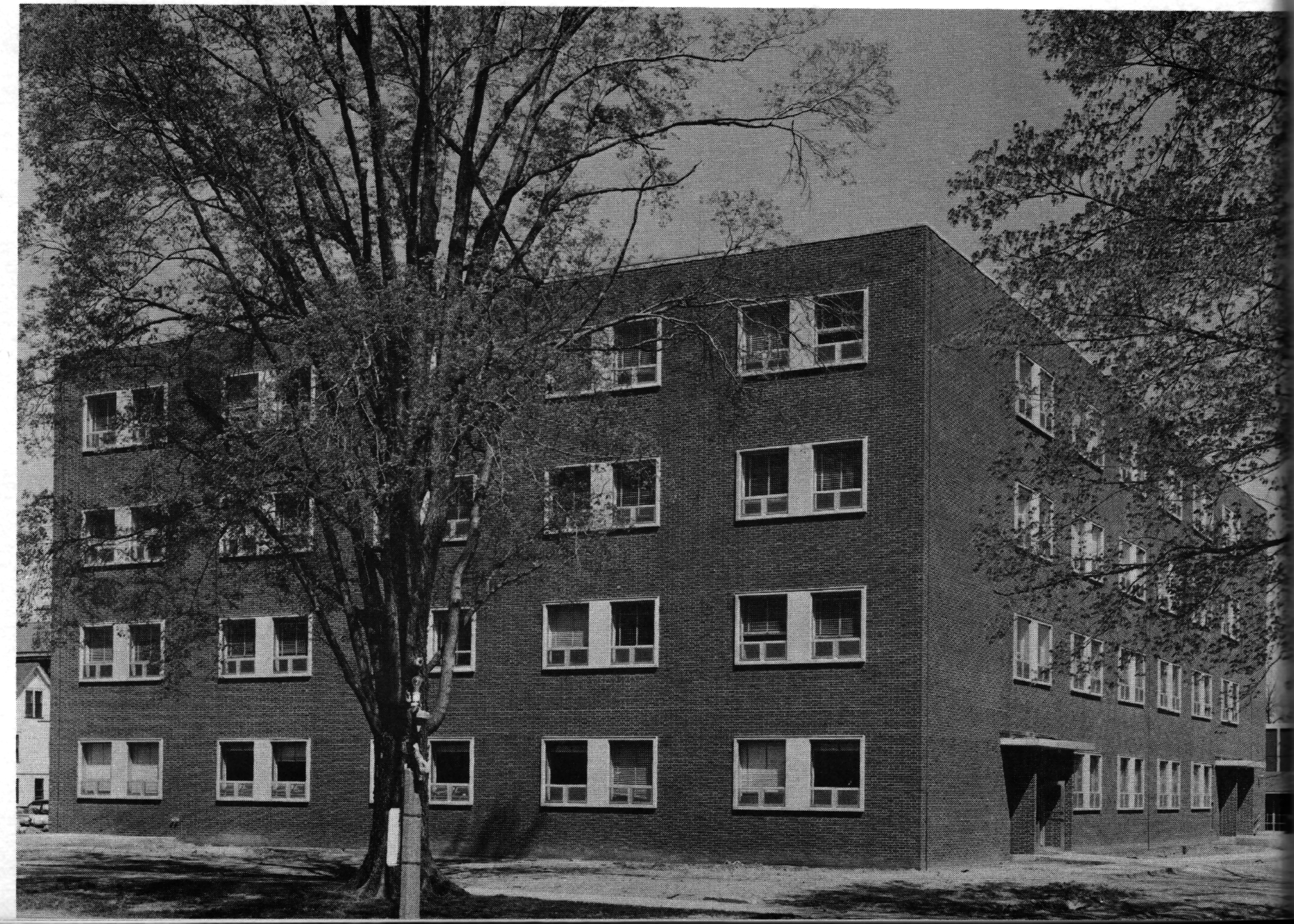
6.

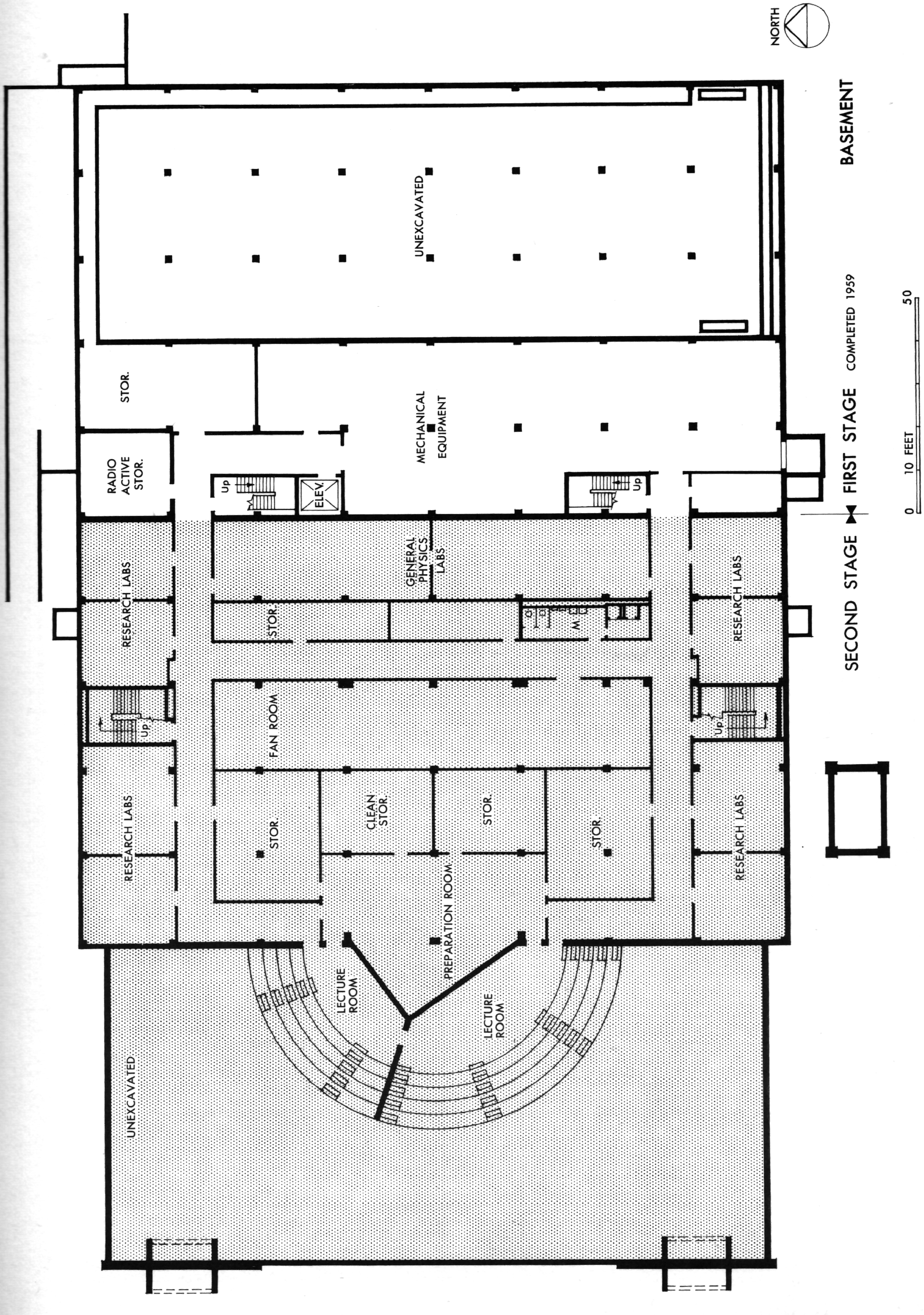
Physics Building
University of Illinois
Urbana, Illinois

Architects:	Shaw, Metz and Associates Chicago, Illinois
Completed:	1st stage—September 1959 2nd stage— funds not allocated
Gross Area of Building:	1st stage —78,000 sq. ft. 2nd stage—98,200 Total —176,200
Total Cost of Building:	$1,880,000—1st stage*
Air Conditioning:	Duct only installed in first stage; air conditioning to be completed in second stage.

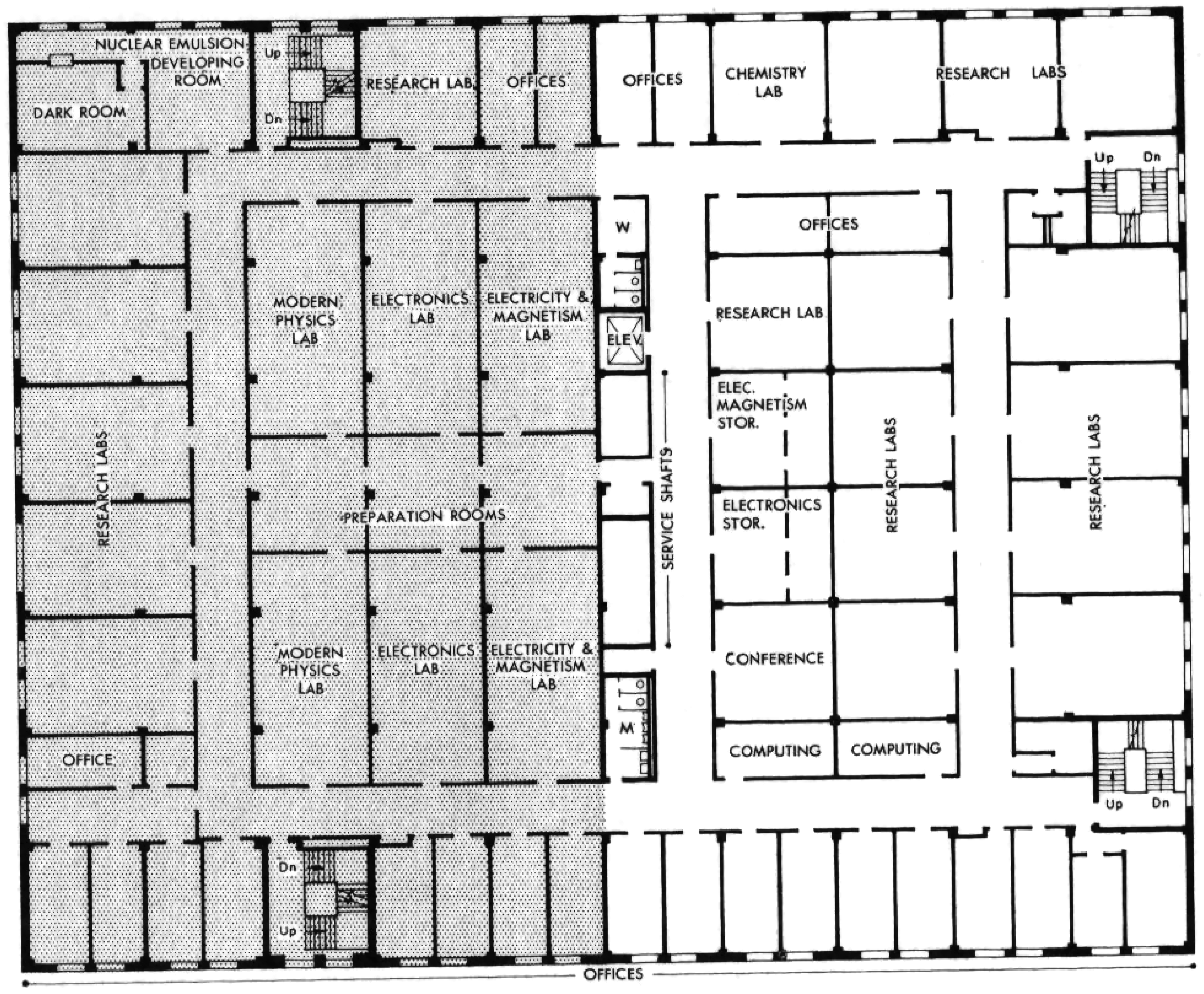
* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

Southeast corner of the building at completion of first stage. (See following pages for floor plans.)

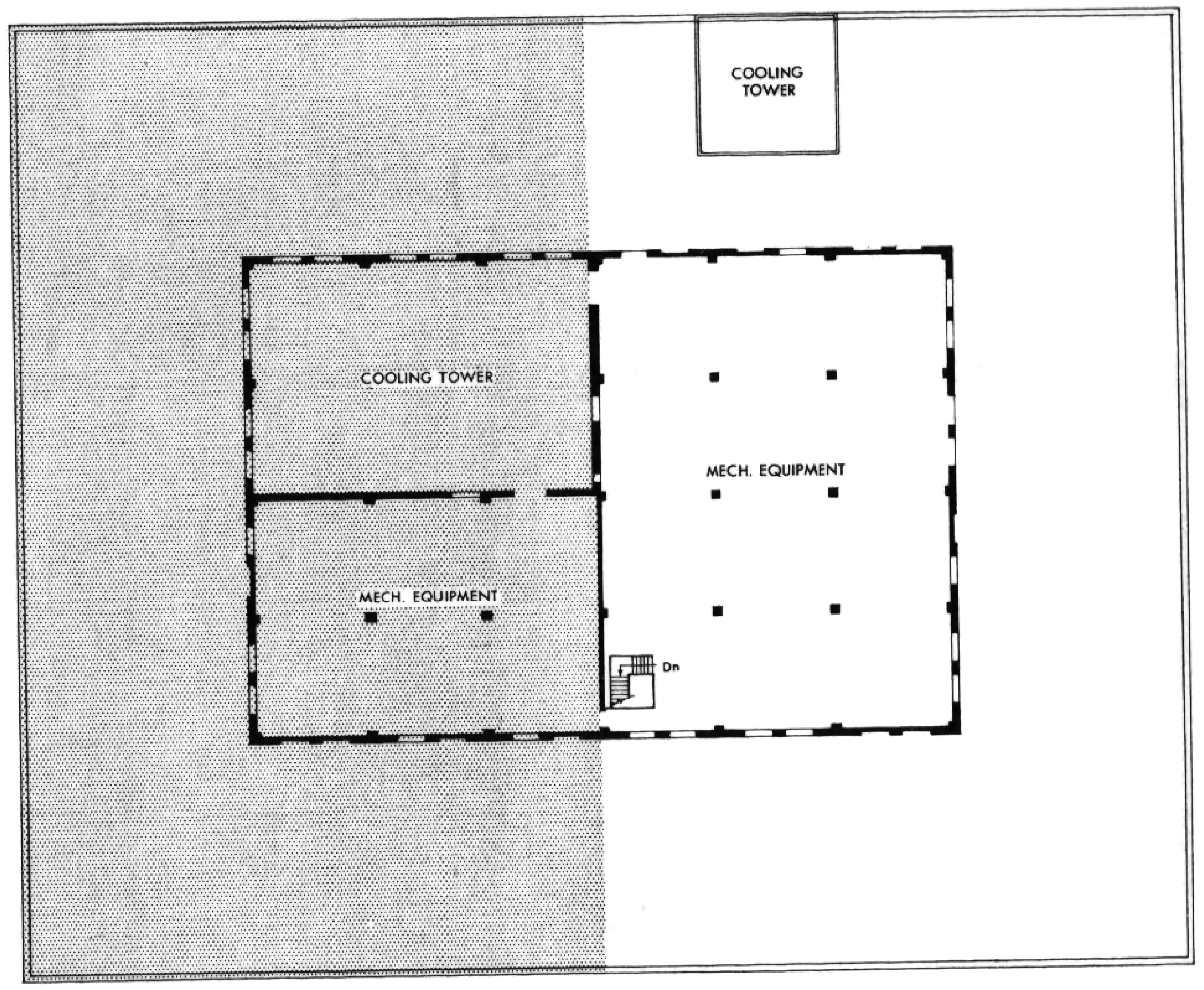



NORTH
BASEMENT
SECOND STAGE
FIRST STAGE
COMPLETED 1959
0
10
FEET
50
UNEXCAVATED
STOR.
MECHANICAL EQUIPMENT
RADIO ACTIVE STOR.
Up
ELEV.
Up
GENERAL PHYSICS LABS
RESEARCH LABS
STOR.
RESEARCH LABS
Up
Up
FAN ROOM
RESEARCH LABS
STOR.
CLEAN STOR.
STOR.
STOR.
RESEARCH LABS
PREPARATION ROOM
LECTURE ROOM
LECTURE ROOM
UNEXCAVATED

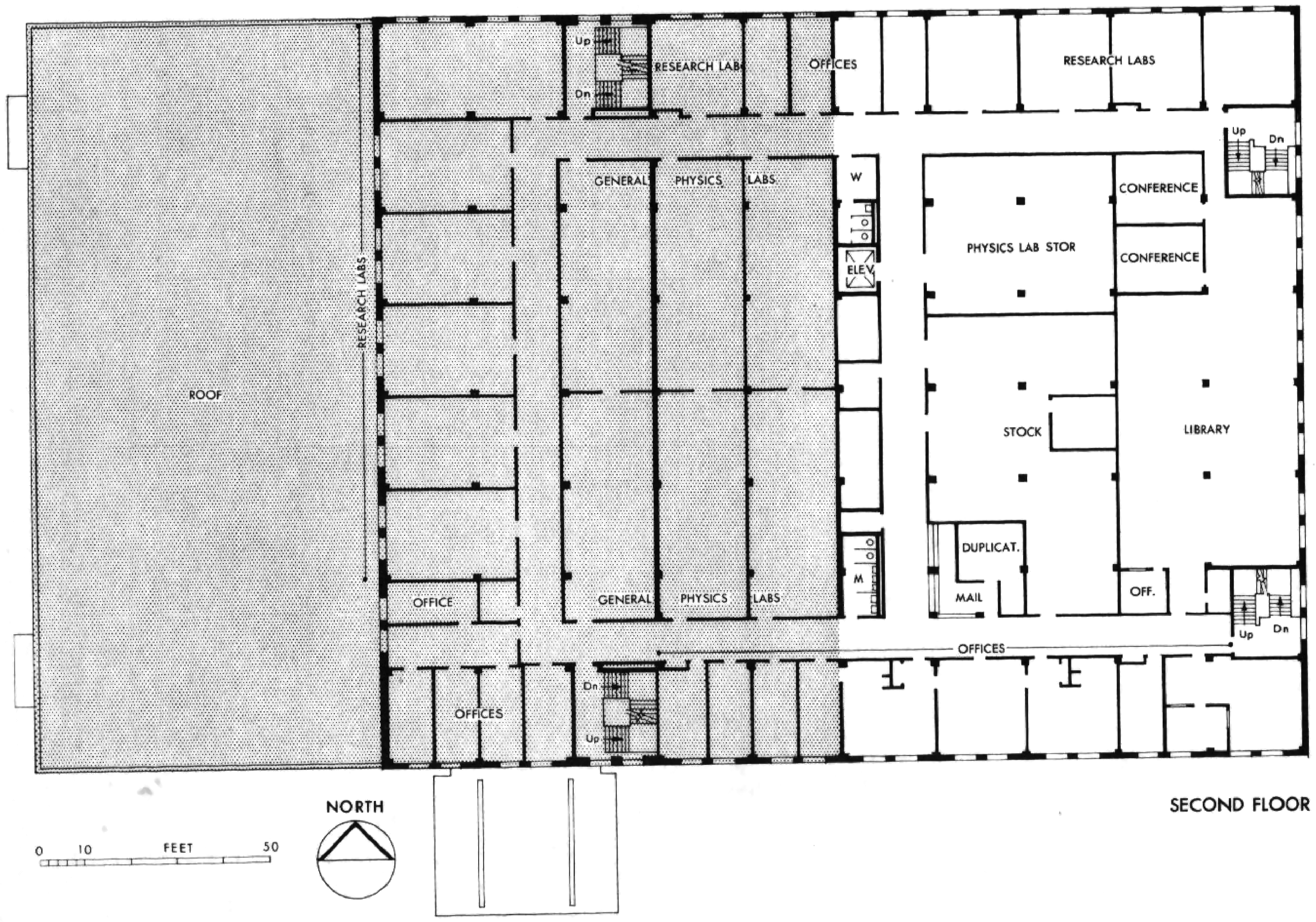
6. (Continued)
Physics Building, University of Illinois


NUCLEAR EMULSION DEVELOPING ROOM
DARK ROOM
RESEARCH LAB
OFFICES
OFFICES
CHEMISTRY LAB
RESEARCH LABS
Up
Dn
OFFICES
W
MODERN PHYSICS LAB
ELECTRONICS LAB
ELECTRICITY & MAGNETISM LAB
ELEV
RESEARCH LAB
ELEC. MAGNETISM STOR.
ELECTRONICS STOR.
RESEARCH LABS
RESEARCH LABS
SERVICE SHAFTS
PREPARATION ROOMS
MODERN PHYSICS LAB
ELECTRONICS LAB
ELECTRICITY & MAGNETISM LAB
CONFERENCE
M
COMPUTING
COMPUTING
OFFICE
OFFICES

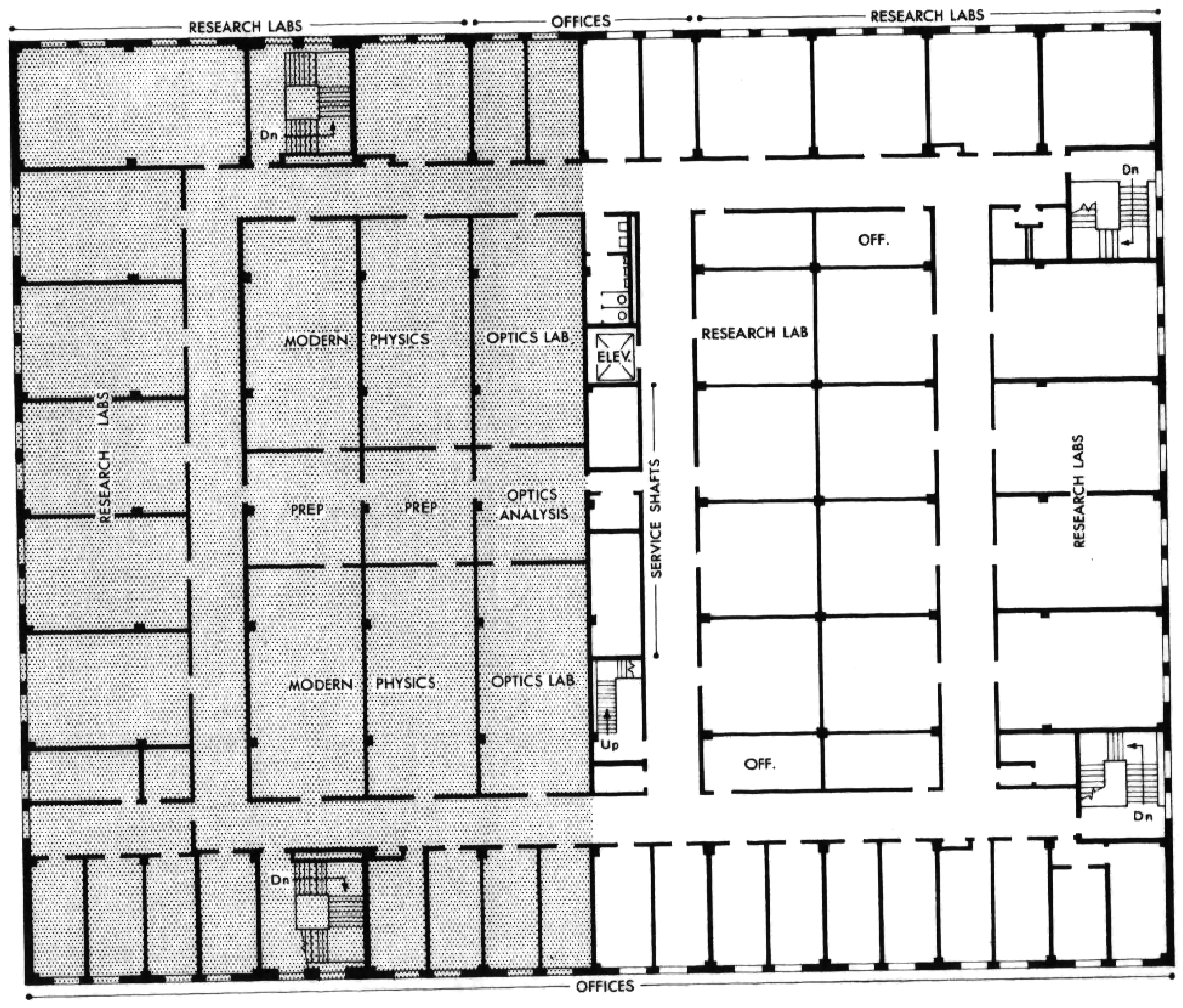
THIRD FLOOR


COOLING TOWER
COOLING TOWER
MECH. EQUIPMENT
MECH. EQUIPMENT
Dn

PENTHOUSE & ROOF

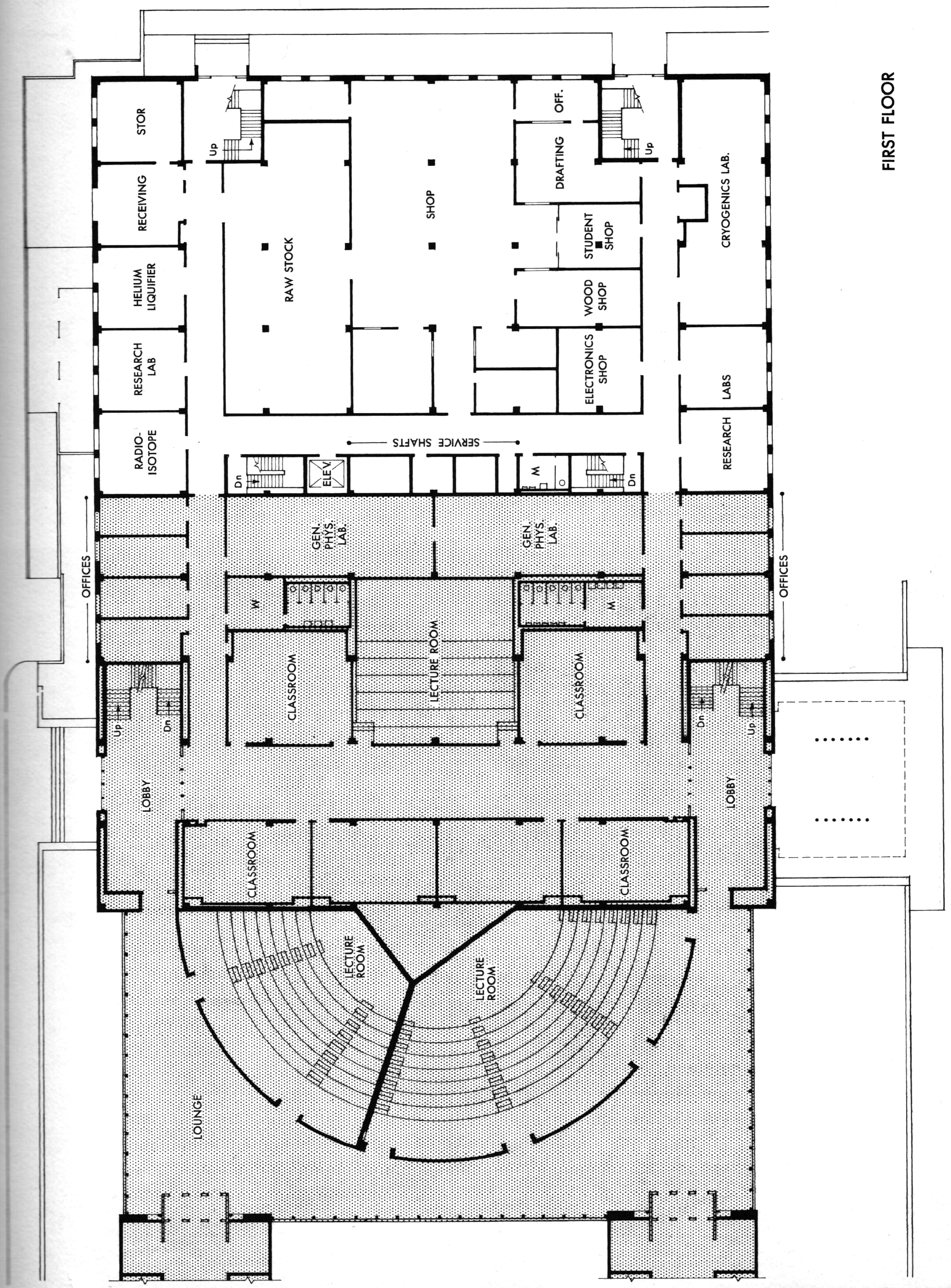

RESEARCH LAB
OFFICES
RESEARCH LABS
Up
Dn
ROOF
RESEARCH LABS
W
GENERAL
PHYSICS
LABS
ELEV
PHYSICS LAB STOR
CONFERENCE
CONFERENCE
STOCK
LIBRARY
DUPLICAT.
MAIL
OFF.
M
GENERAL
PHYSICS
LABS
OFFICE
OFFICES
OFFICES
NORTH
0
10
FEET
50

SECOND FLOOR


RESEARCH LABS
OFFICES
RESEARCH LABS
Dn
Up
OFF.
MODERN
PHYSICS
OPTICS LAB
ELEV
RESEARCH LAB
RESEARCH LABS
PREP
PREP
OPTICS ANALYSIS
SERVICE SHAFTS
RESEARCH LABS
MODERN
PHYSICS
OPTICS LAB
OFF.
OFFICES

FOURTH FLOOR

FIRST FLOOR



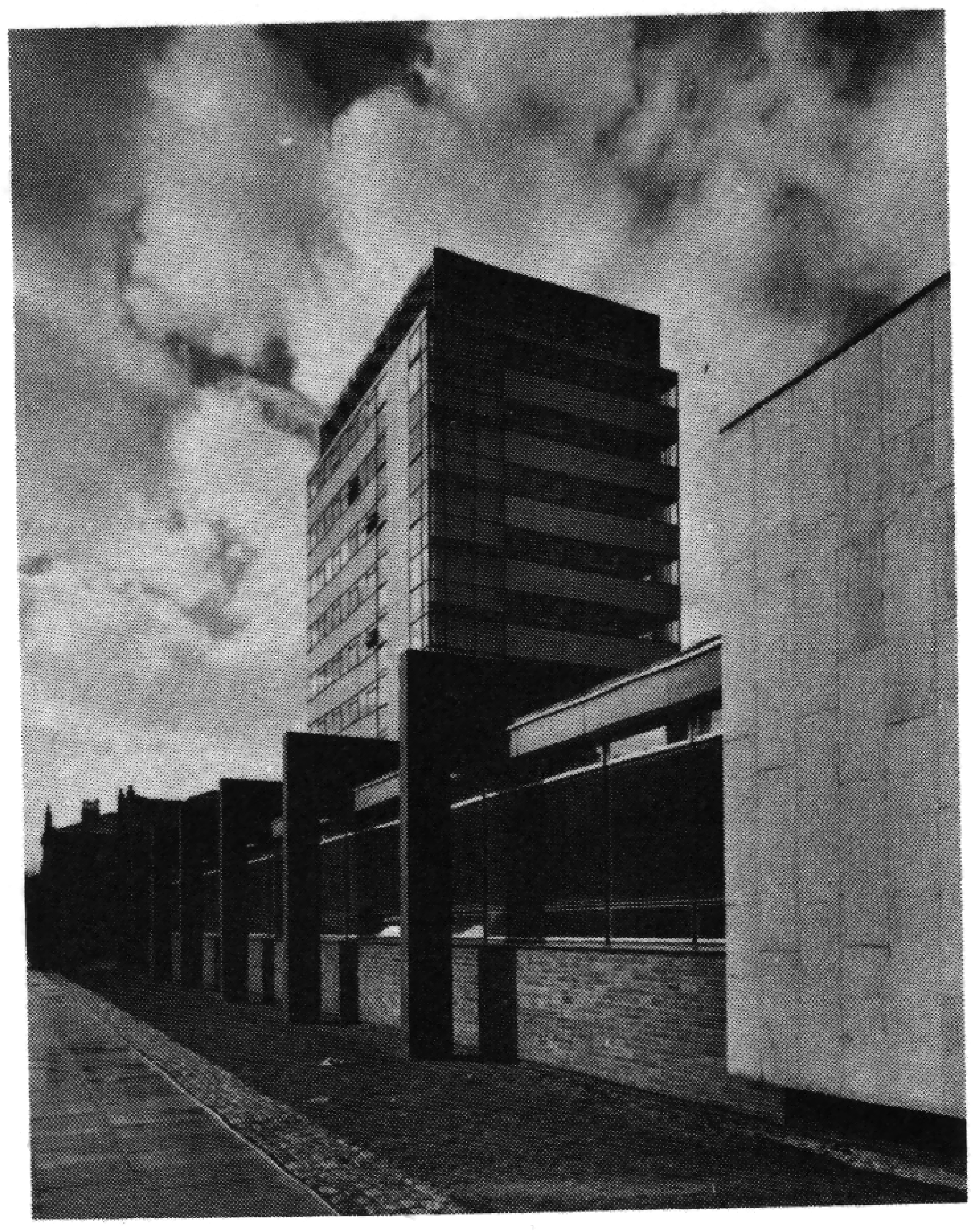
STOR
RECEIVING
HELIUM LIQUIFIER
RESEARCH LAB
RADIO-ISOTOPE
Up
RAW STOCK
SHOP
OFF.
DRAFTING
STUDENT SHOP
WOOD SHOP
ELECTRONICS SHOP
Up
CRYOGENICS LAB.
LABS
RESEARCH
SERVICE SHAFTS
Dn
ELEV
W
Dn
OFFICES
GEN. PHYS. LAB.
GEN. PHYS. LAB.
OFFICES
W
W
CLASSROOM
LECTURE ROOM
CLASSROOM
Up
Dn
Dn
Up
LOBBY
LOBBY
CLASSROOM
CLASSROOM
LECTURE ROOM
LECTURE ROOM
LOUNGE

7.

The Chadwick Laboratory
University of Liverpool
Liverpool, England

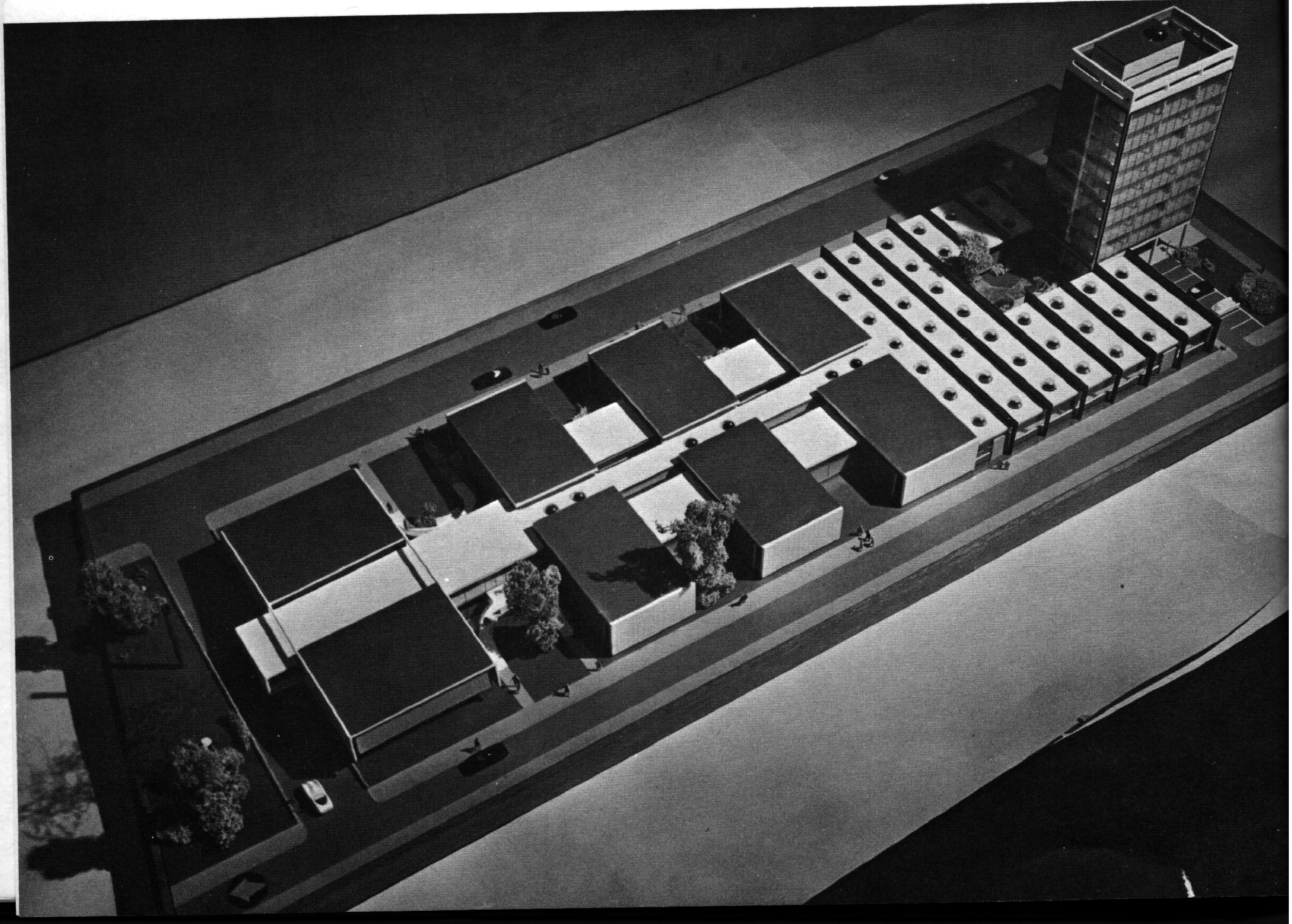
Architects:	Sir Basil Spence, R.A., R.D.I., P.P.R.I.B.A., One Canonbury Place, London N.1.
Completed:	December 1959
Gross Area of Building:	94,500 sq. ft.
Total Cost of Building:	494,482 Pounds Sterling*
Air Conditioning:	None

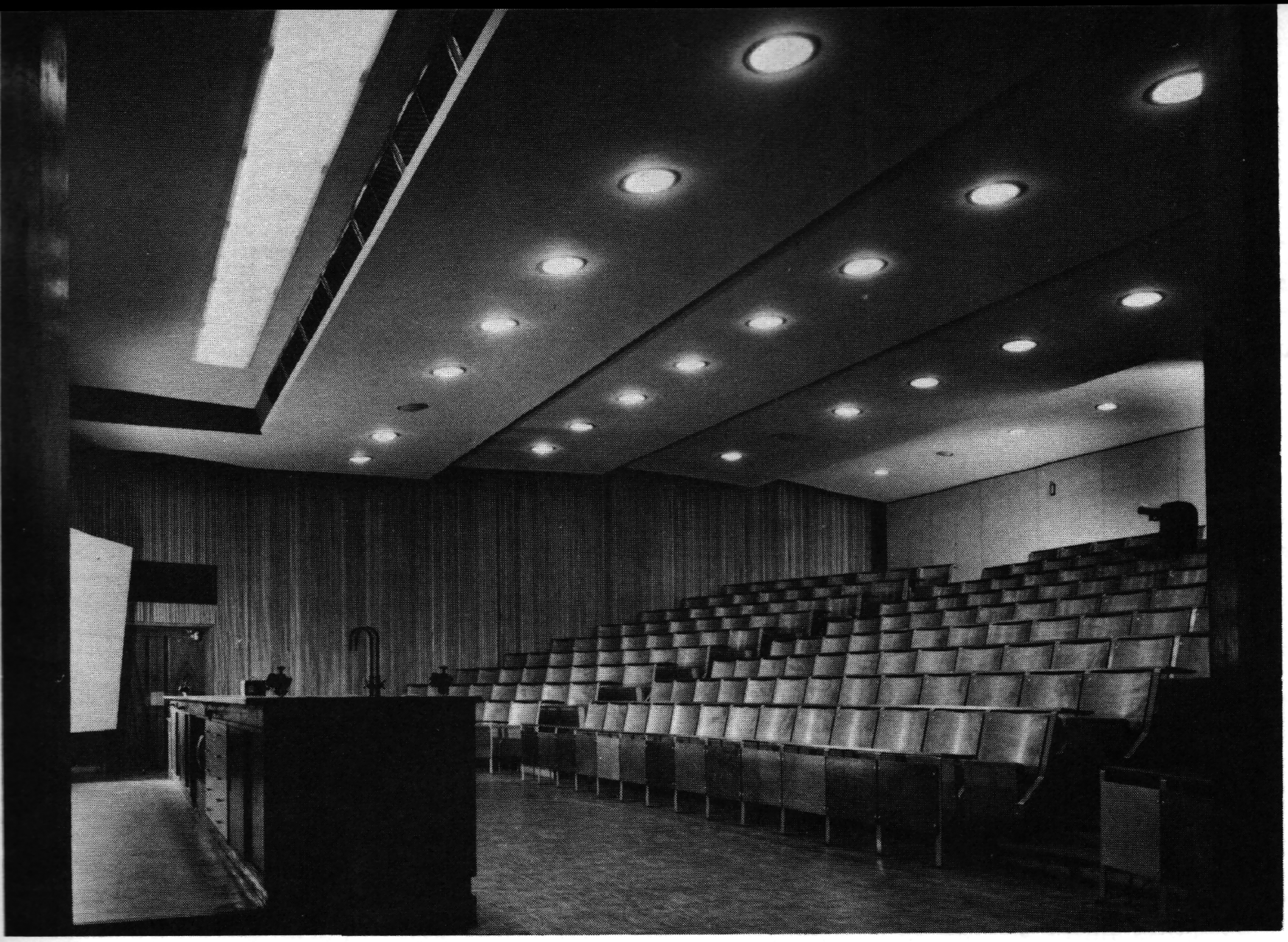
* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.



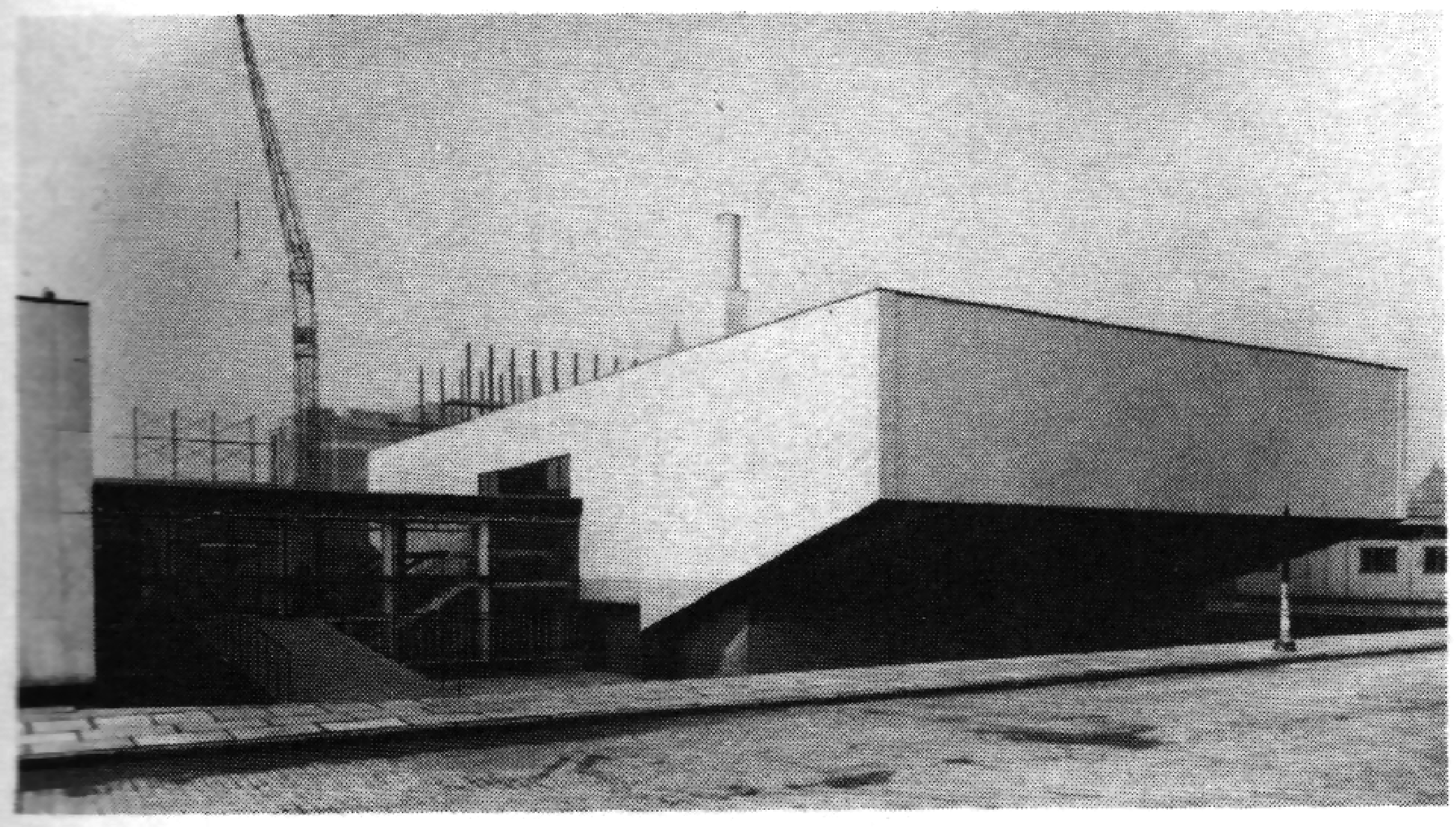
Northeast corner of 7-story tower containing offices and laboratories. Library and acoustic laboratory in foreground.

Model of building.

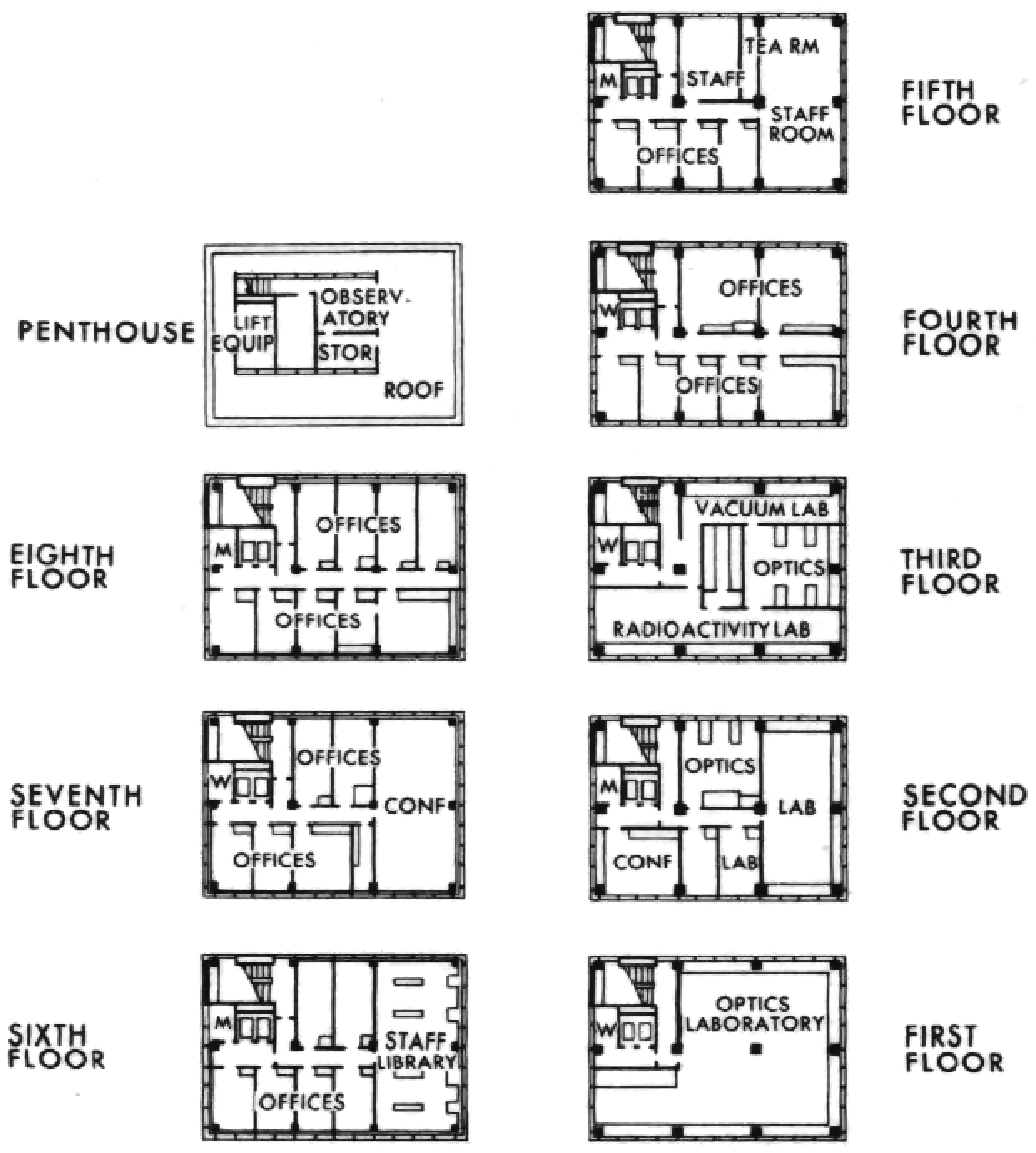


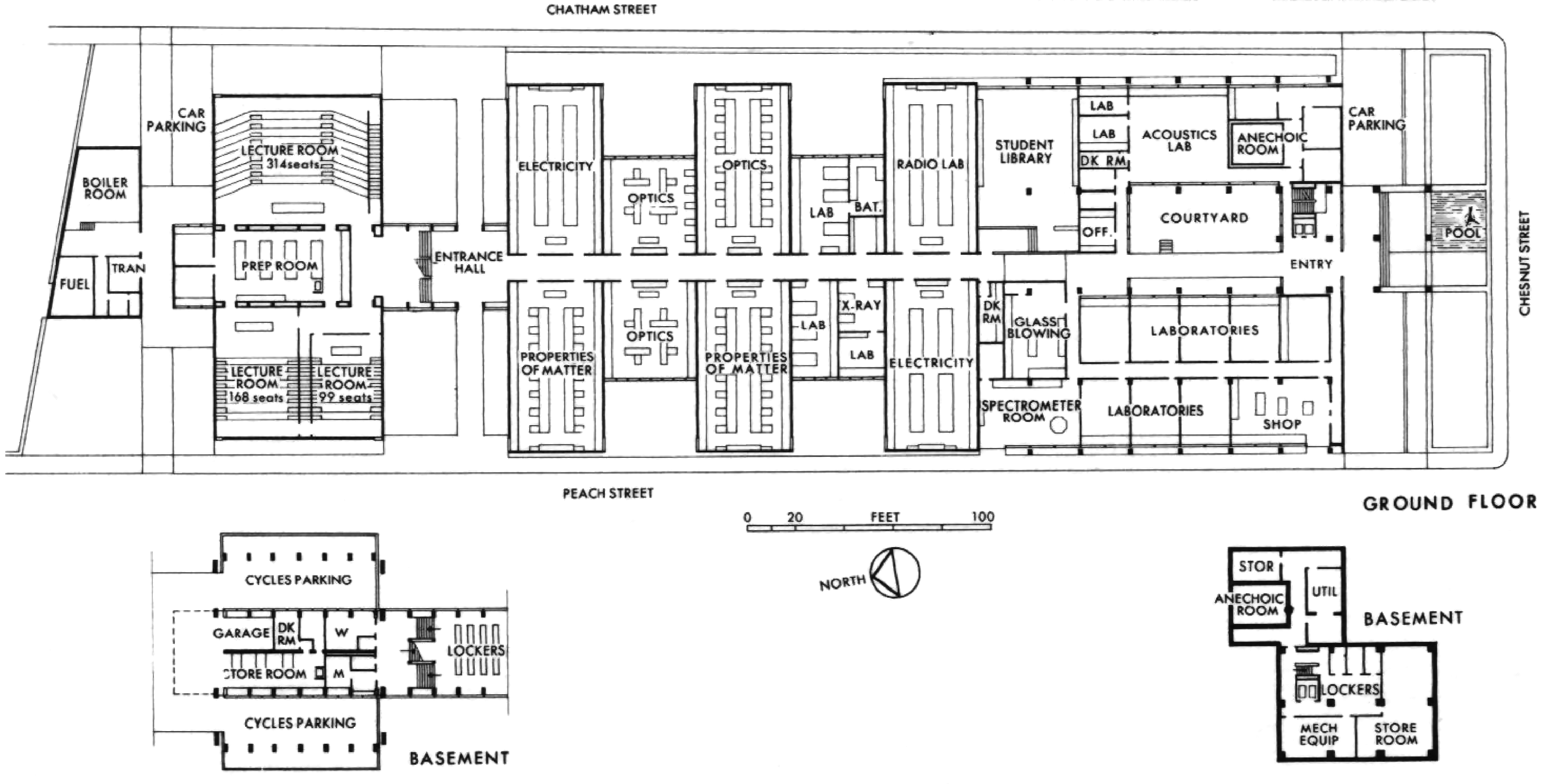


Large lecture theater. Note distance between elevated demonstration table and first row of seats.



Students' entrance and lecture theatre block.



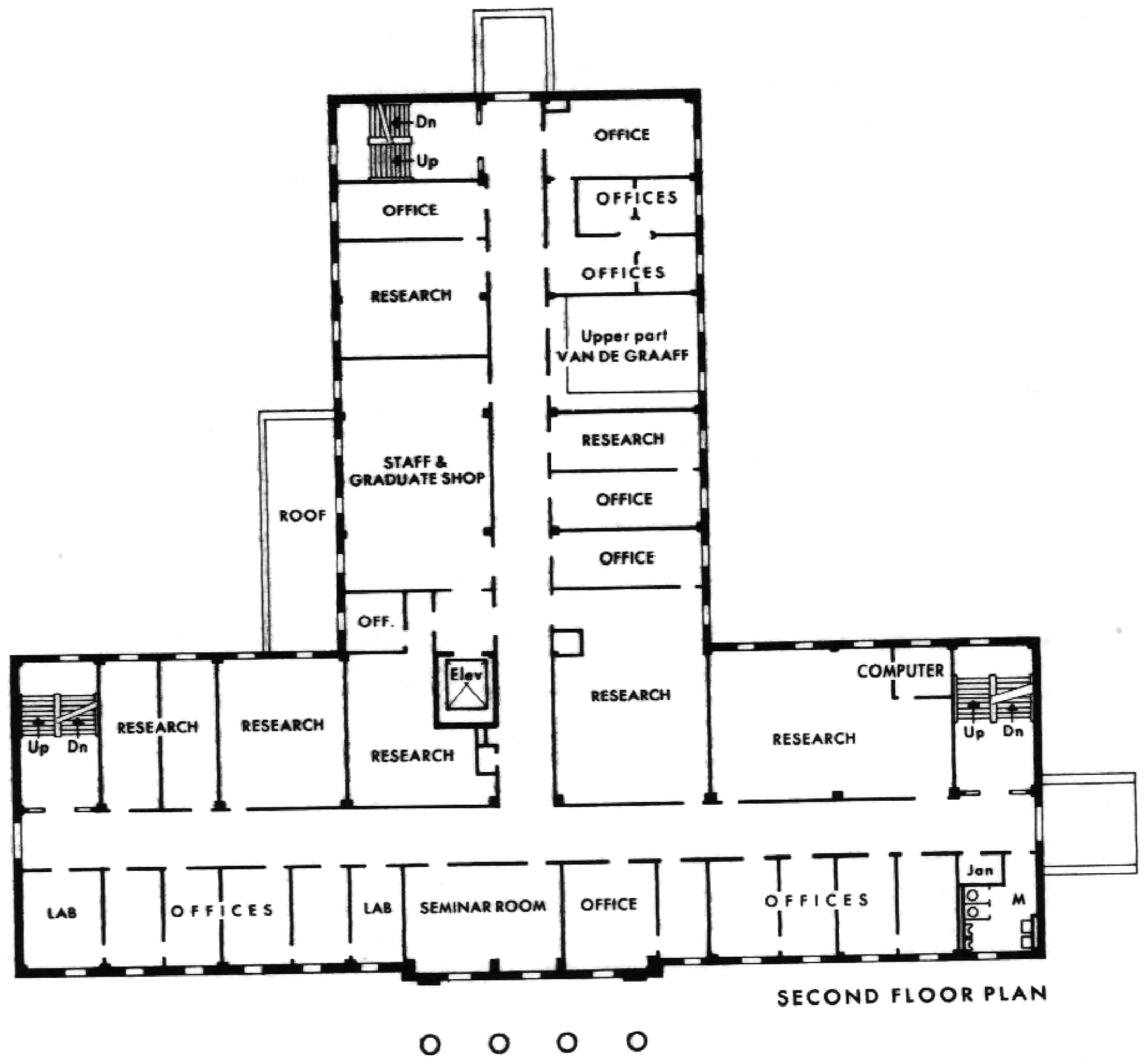

FIFTH FLOOR
TEA RM
STAFF
STAFF ROOM
OFFICES
PENTHOUSE
LIFT EQUIP
OBSERV-ATORY
STOR
ROOF
FOURTH FLOOR
OFFICES
EIGHTH FLOOR
THIRD FLOOR
VACUUM LAB
OPTICS
RADIOACTIVITY LAB
SEVENTH FLOOR
CONF
SECOND FLOOR
LAB
SIXTH FLOOR
STAFF LIBRARY
FIRST FLOOR
OPTICS LABORATORY
W
M
CHATHAM STREET
CAR PARKING
BOILER ROOM
FUEL
TRAN
LECTURE ROOM 314 seats
PREP ROOM
LECTURE ROOM 168 seats
LECTURE ROOM 99 seats
ENTRANCE HALL
ELECTRICITY
OPTICS
PROPERTIES OF MATTER
LAB
BAT.
X-RAY
RADIO LAB
STUDENT LIBRARY
DK RM
ACOUSTICS LAB
ANECHOIC ROOM
OFF.
COURTYARD
ENTRY
POOL
CHESNUT STREET
GLASS BLOWING
LABORATORIES
SPECTROMETER ROOM
SHOP
PEACH STREET
GROUND FLOOR
0 20 FEET 100
NORTH
CYCLES PARKING
GARAGE
STORE ROOM
LOCKERS
BASEMENT
STOR
UTIL
MECH EQUIP
STORE ROOM

8.

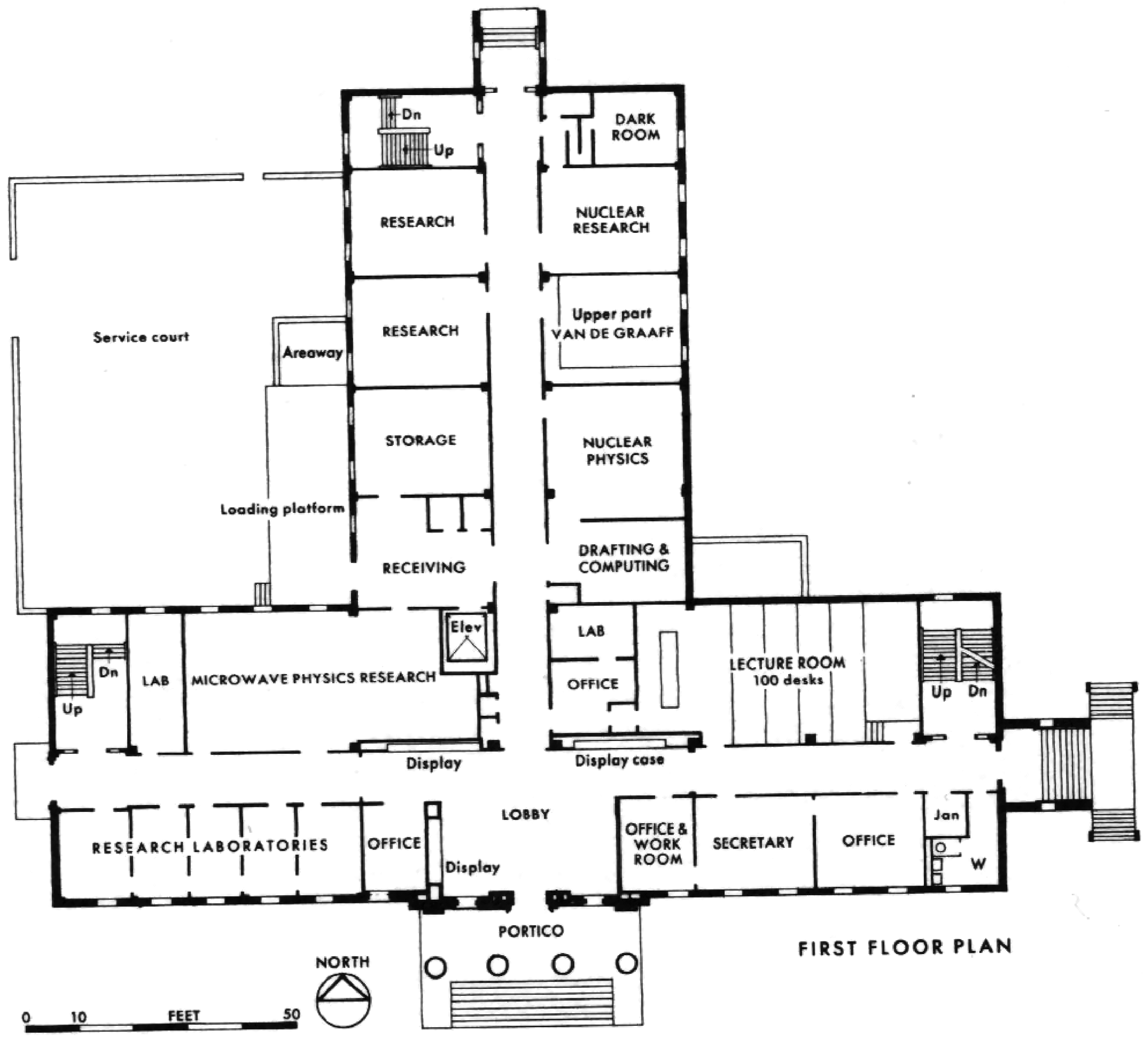
Physics Building
University of Maryland
College Park, Maryland

Architects:	Hall, Border and Donaldson Baltimore, Maryland
Date of Completion:	First stage—completed Second stage—September 1963
Gross Area of Building:	First Stage —76,000 sq. ft. Second Stage—48,307 sq. ft.
Total Cost of Building:	First Stage —$1,300,000*-** Second Stage—$800,000**
Air Conditioning:	None—but ducts are provided, consisting of an "all air" dual duct system. Terminal mixing boxes will be located either under windows or over doors. Rooms will have individual controls. Shielded laboratory and associated rooms in East Wing will have separate air conditioning system employing a multi-zone type of air handling unit.

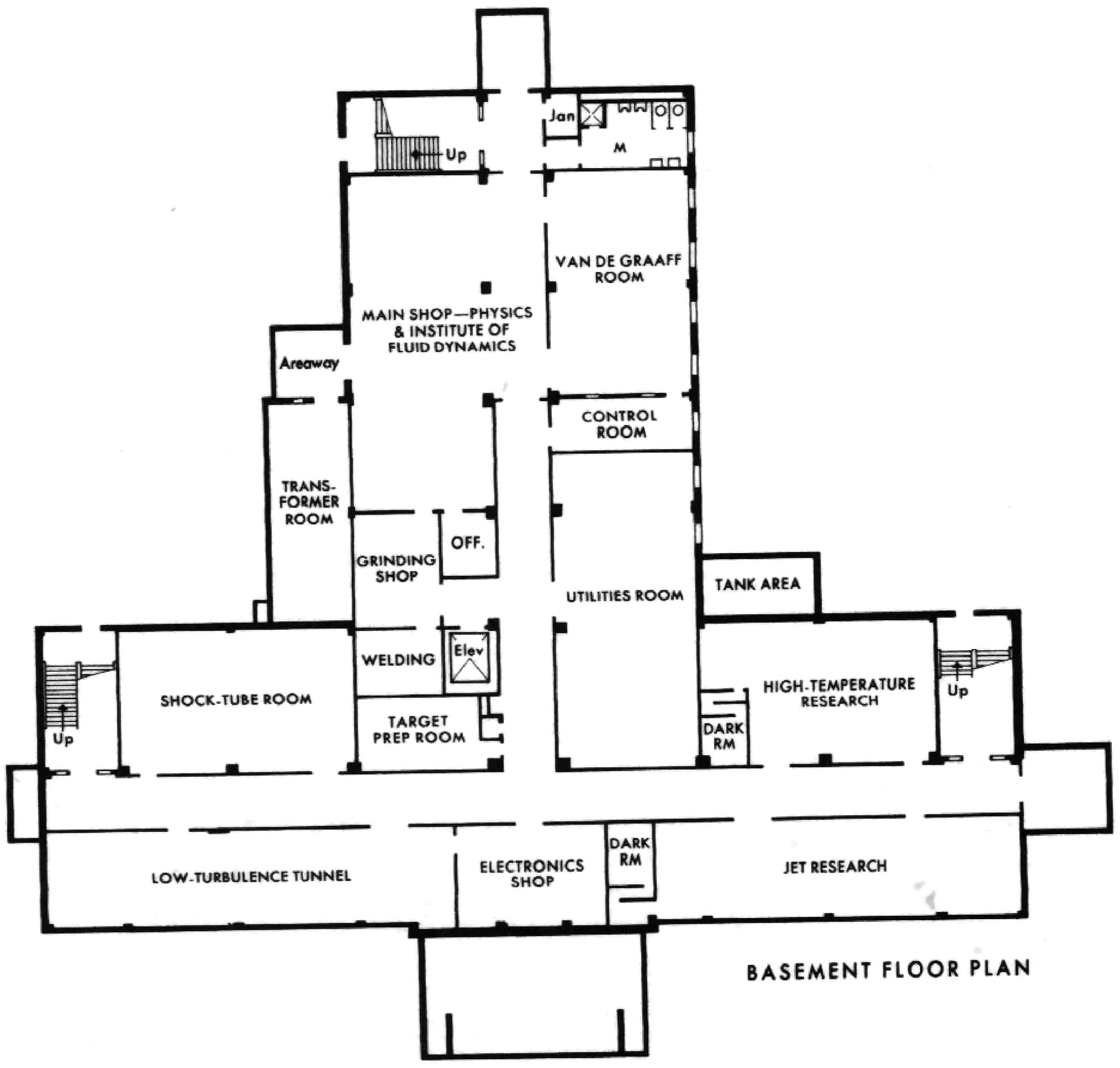
* Includes neutron pit.
** Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.


Dn
Up
OFFICE
OFFICES
OFFICES
OFFICE
RESEARCH
Upper part VAN DE GRAAFF
RESEARCH
STAFF & GRADUATE SHOP
OFFICE
OFFICE
ROOF
OFF.
Elev
COMPUTER
RESEARCH
RESEARCH
RESEARCH
RESEARCH
RESEARCH
Up Dn
Up Dn
LAB
OFFICES
LAB
SEMINAR ROOM
OFFICE
OFFICES
Jan
M

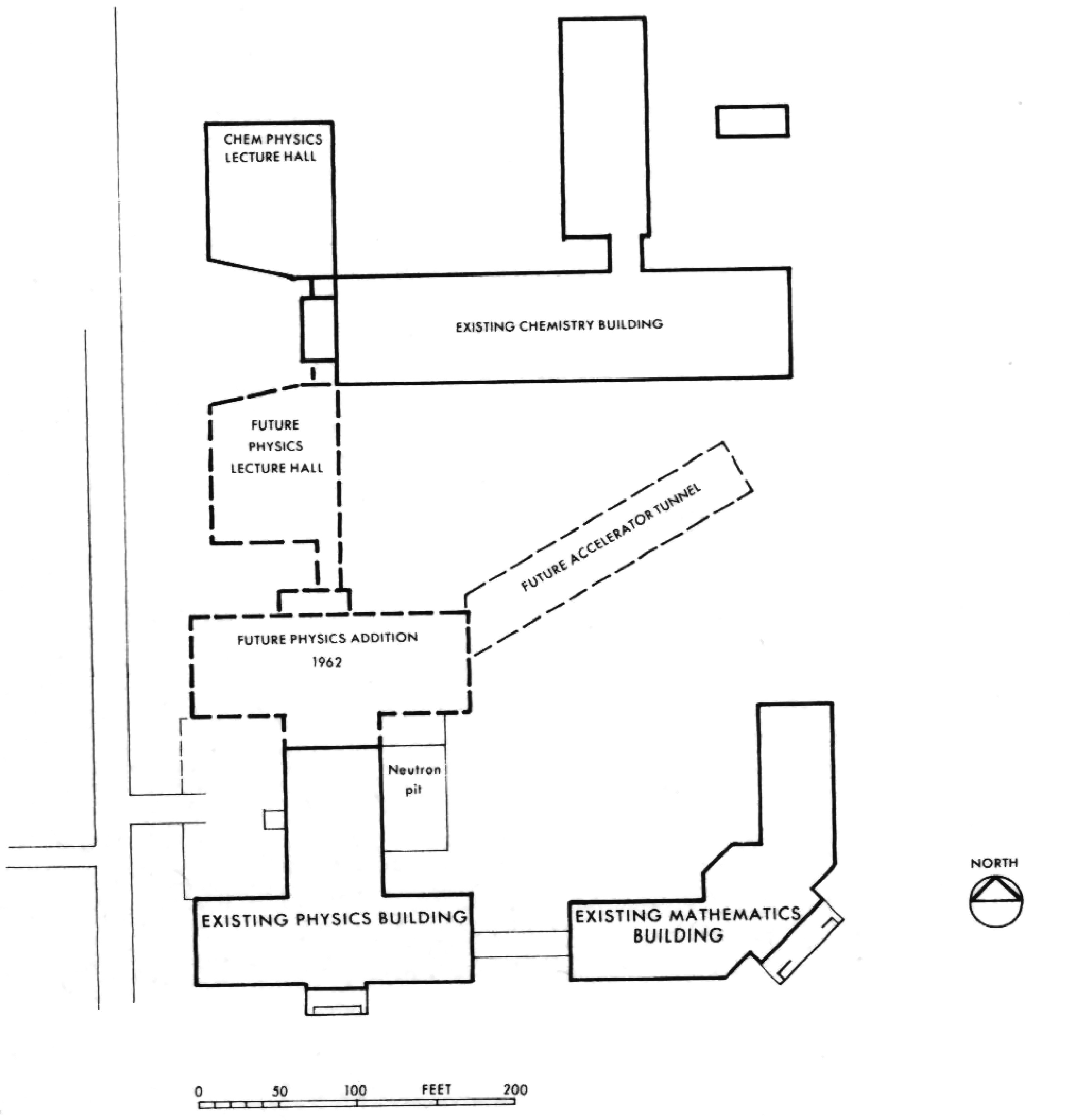
SECOND FLOOR PLAN


Dn
Up
DARK ROOM
RESEARCH
NUCLEAR RESEARCH
Service court
Areaway
RESEARCH
Upper part VAN DE GRAAFF
STORAGE
NUCLEAR PHYSICS
Loading platform
RECEIVING
DRAFTING & COMPUTING
Elev
LAB
Dn
Up
LAB
MICROWAVE PHYSICS RESEARCH
OFFICE
LECTURE ROOM 100 desks
Up Dn
Display
Display case
LOBBY
RESEARCH LABORATORIES
OFFICE
Display
OFFICE & WORK ROOM
SECRETARY
OFFICE
Jan
W
PORTICO
NORTH
0 10 FEET 50

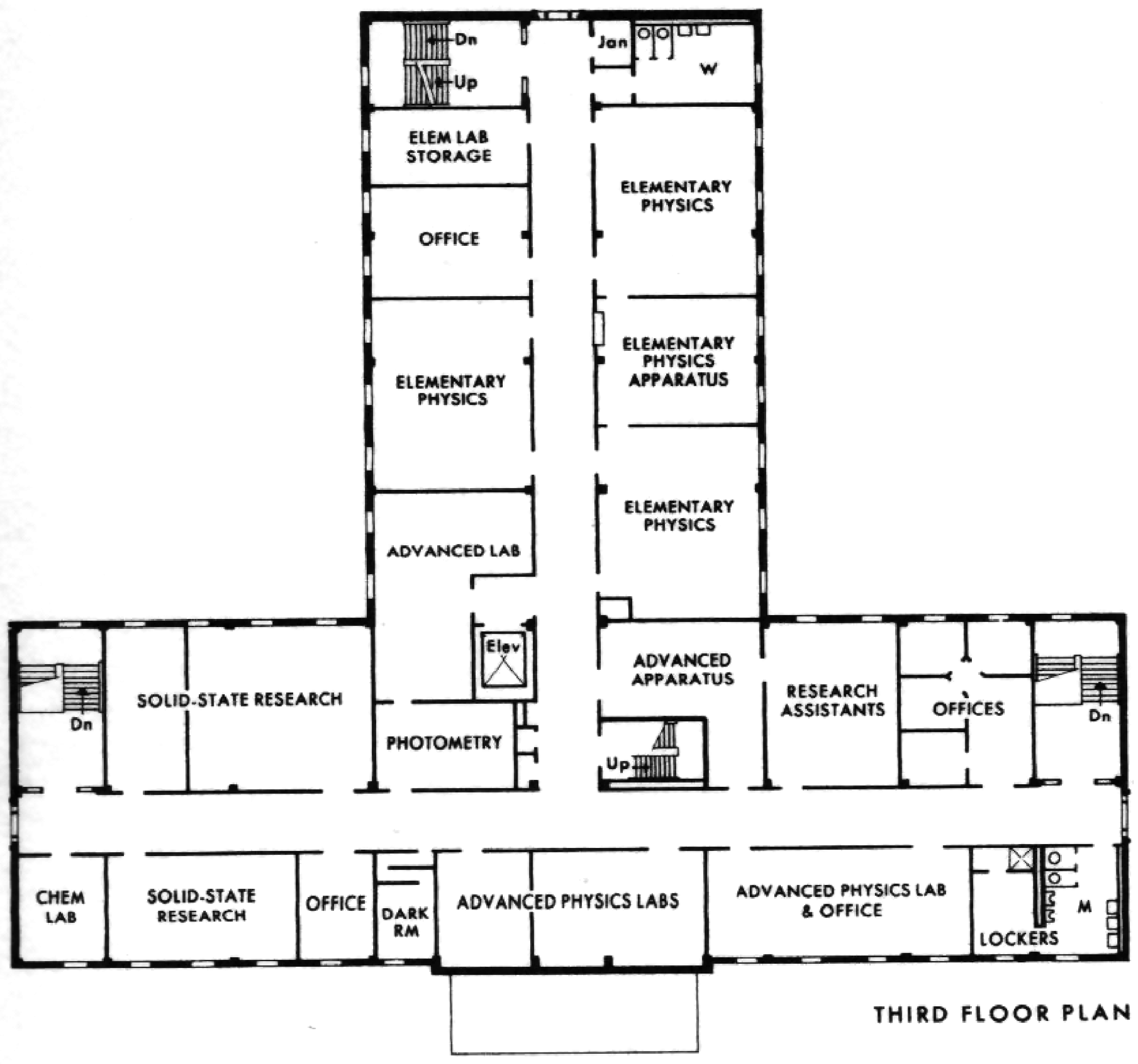
FIRST FLOOR PLAN


Jan
M
Up
VAN DE GRAAFF ROOM
MAIN SHOP—PHYSICS & INSTITUTE OF FLUID DYNAMICS
Areaway
CONTROL ROOM
TRANS-FORMER ROOM
GRINDING SHOP
OFF.
UTILITIES ROOM
TANK AREA
WELDING
Elev
SHOCK-TUBE ROOM
TARGET PREP ROOM
HIGH-TEMPERATURE RESEARCH
DARK RM
Up
Up
LOW-TURBULENCE TUNNEL
ELECTRONICS SHOP
DARK RM
JET RESEARCH

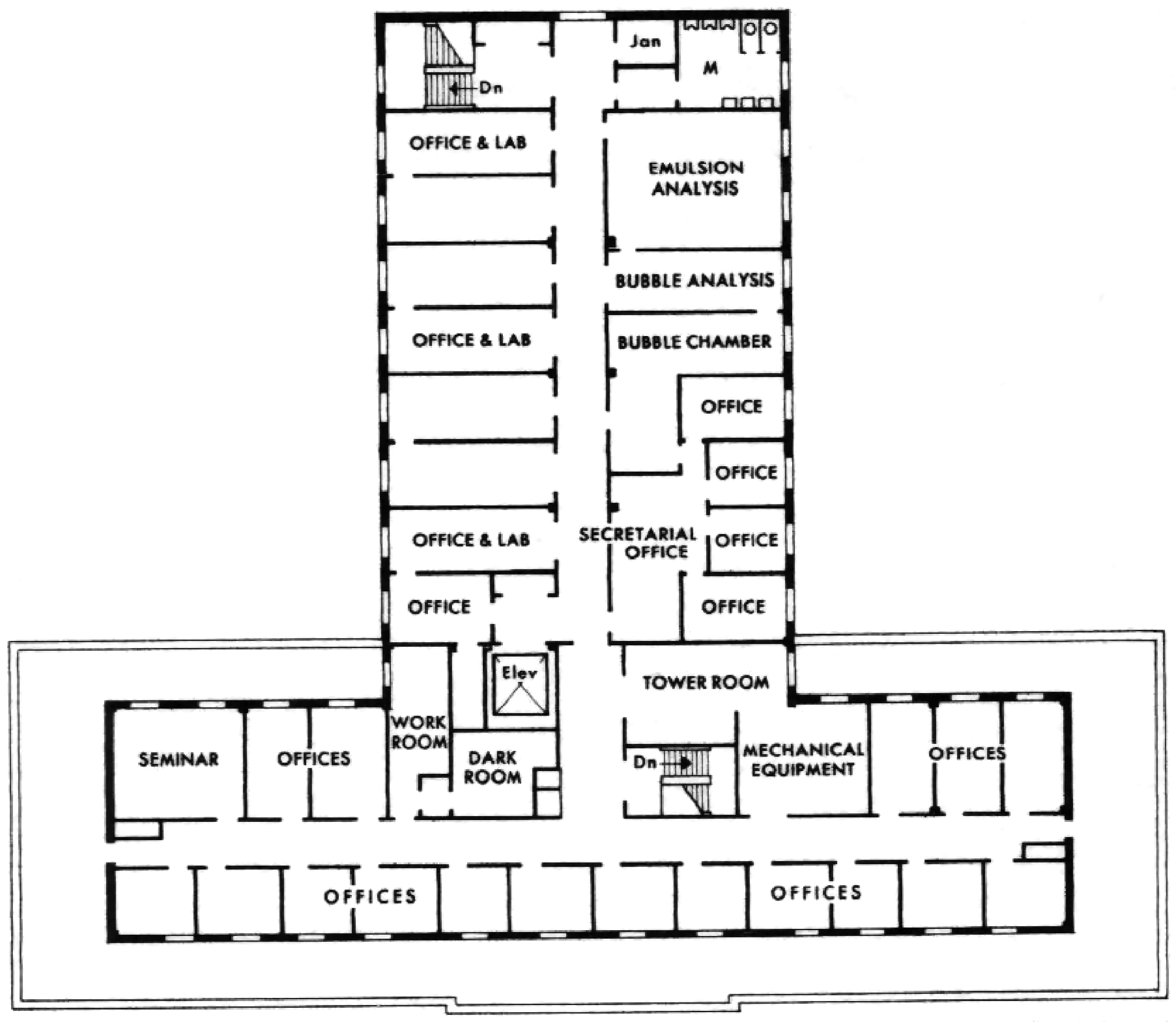
BASEMENT FLOOR PLAN


CHEM PHYSICS LECTURE HALL
EXISTING CHEMISTRY BUILDING
FUTURE PHYSICS LECTURE HALL
FUTURE ACCELERATOR TUNNEL
FUTURE PHYSICS ADDITION 1962
Neutron pit
EXISTING PHYSICS BUILDING
EXISTING MATHEMATICS BUILDING
NORTH
0 50 100 FEET 200

PLOT PLAN


Dn
Up
Jan
W
ELEM LAB STORAGE
OFFICE
ELEMENTARY PHYSICS
ADVANCED LAB
ELEMENTARY PHYSICS
ELEMENTARY PHYSICS APPARATUS
ELEMENTARY PHYSICS
Elev
Dn
SOLID-STATE RESEARCH
PHOTOMETRY
ADVANCED APPARATUS
Up
RESEARCH ASSISTANTS
OFFICES
Dn
CHEM LAB
SOLID-STATE RESEARCH
OFFICE
DARK RM
ADVANCED PHYSICS LABS
ADVANCED PHYSICS LAB & OFFICE
M
LOCKERS

THIRD FLOOR PLAN


Dn
Jan
M
OFFICE & LAB
EMULSION ANALYSIS
BUBBLE ANALYSIS
OFFICE & LAB
BUBBLE CHAMBER
OFFICE
OFFICE
OFFICE & LAB
SECRETARIAL OFFICE
OFFICE
OFFICE
OFFICE
Elev
TOWER ROOM
SEMINAR
OFFICES
WORK ROOM
DARK ROOM
Dn
MECHANICAL EQUIPMENT
OFFICES
OFFICES
OFFICES

FOURTH FLOOR PLAN

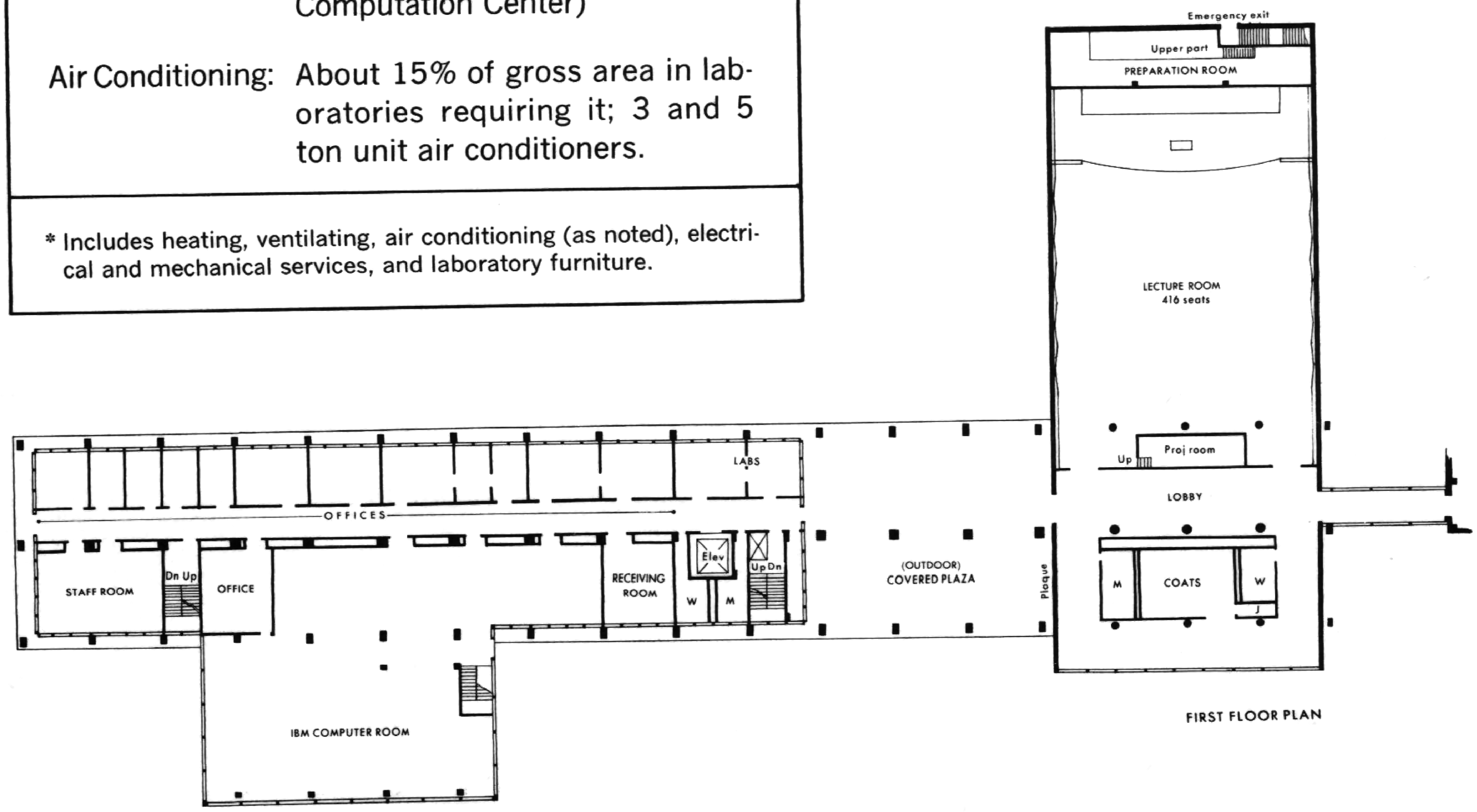
Aerial view of physics building. The penthouse floor has not been completed.

9.

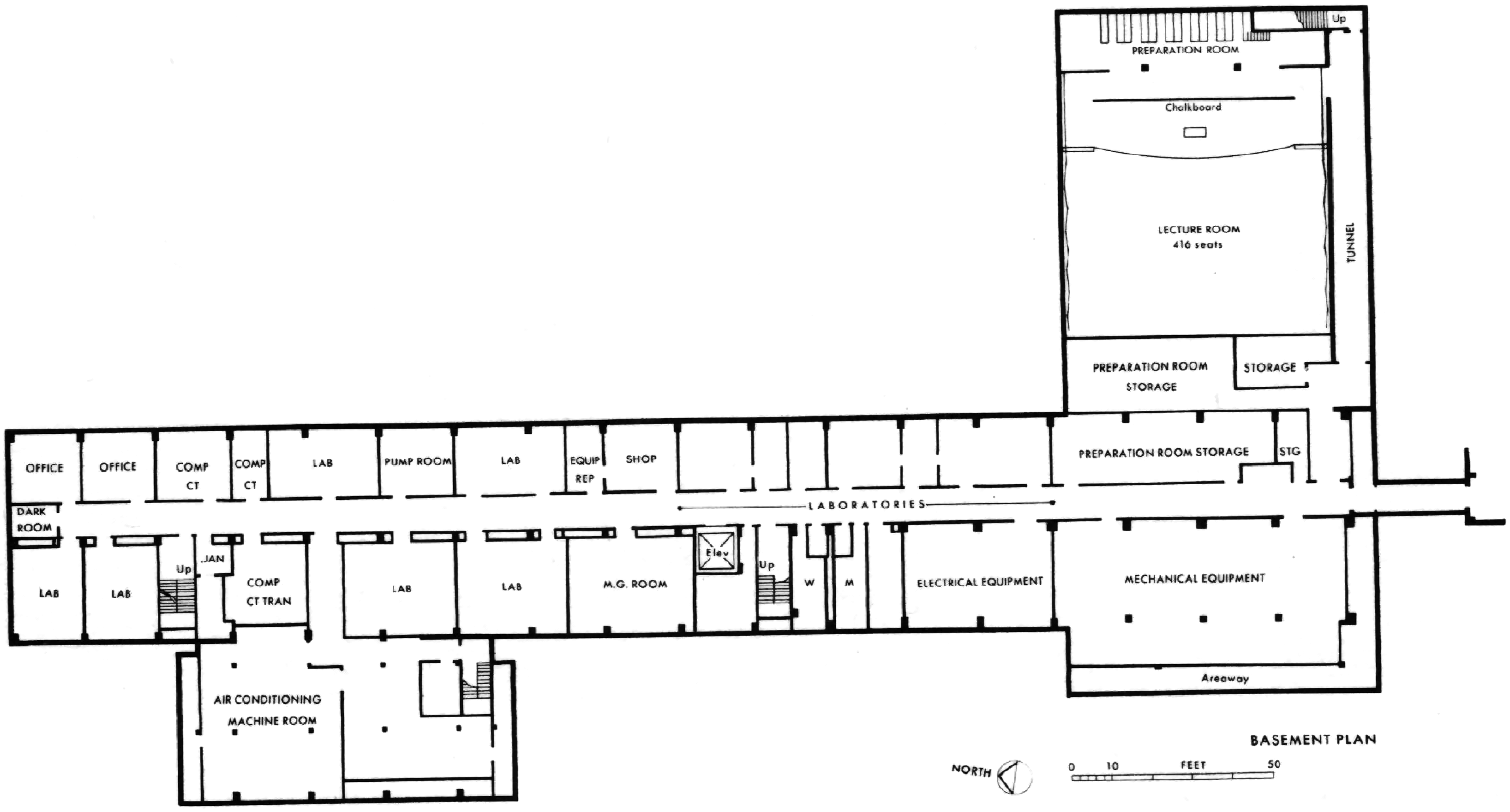
Karl Taylor Compton Laboratories
Massachusetts Institute of Technology
Cambridge, Massachusetts

Architects:	Skidmore, Owings and Merrill New York City, New York
Completed:	June 1957
Gross Area of Building:	114,000 sq. ft. (exclusive of Computation Center)
Total Cost of Building:	$3,234,000* (exclusive of Computation Center)
Air Conditioning:	About 15% of gross area in laboratories requiring it; 3 and 5 ton unit air conditioners.

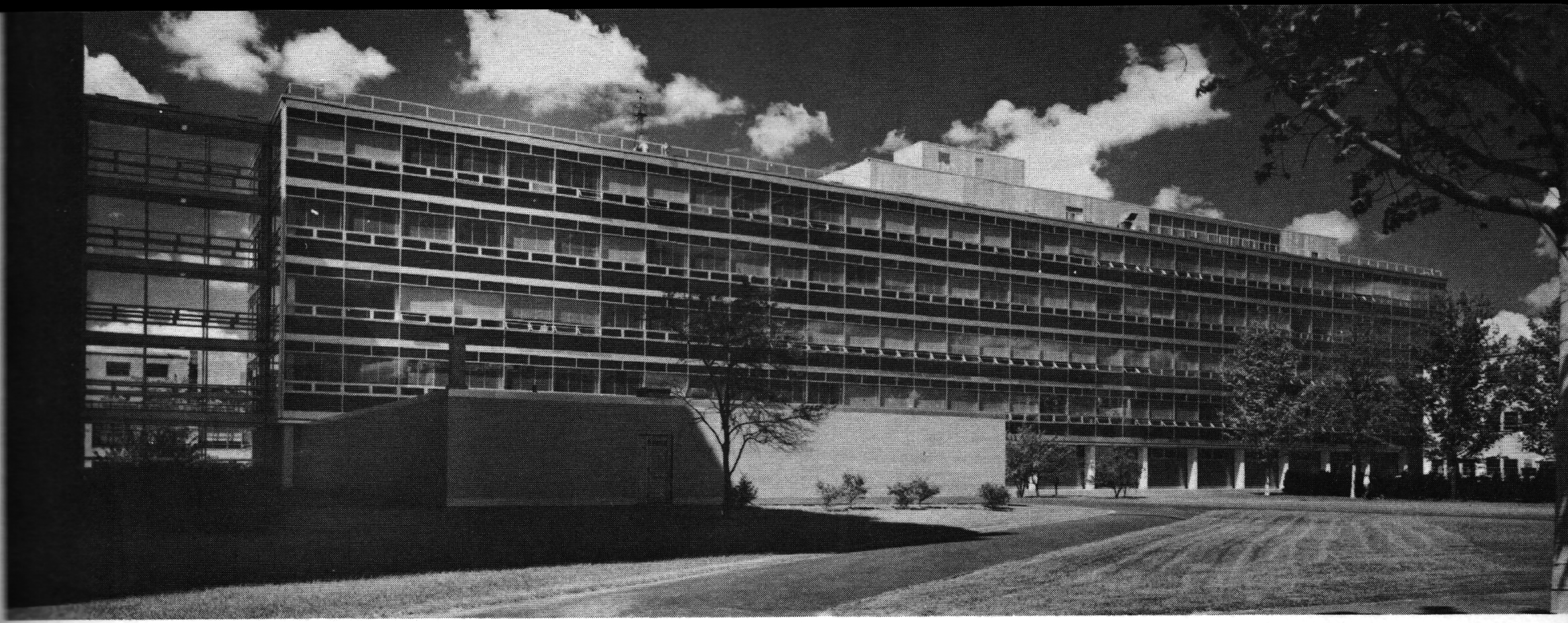
* Includes heating, ventilating, air conditioning (as noted), electrical and mechanical services, and laboratory furniture.


Emergency exit
Upper part
PREPARATION ROOM
LECTURE ROOM
416 seats
Up
Proj room
LOBBY
LABS
OFFICES
STAFF ROOM
Dn Up
OFFICE
RECEIVING ROOM
Elev
Up Dn
W
M
(OUTDOOR) COVERED PLAZA
Plaque
M
COATS
W
J
IBM COMPUTER ROOM

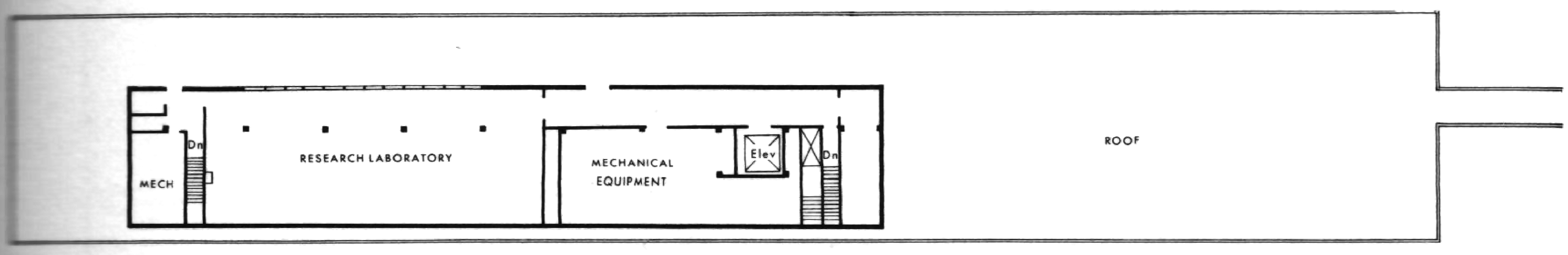
FIRST FLOOR PLAN


Up
PREPARATION ROOM
Chalkboard
LECTURE ROOM
416 seats
TUNNEL
PREPARATION ROOM
STORAGE
STORAGE
OFFICE
OFFICE
COMP CT
COMP CT
LAB
PUMP ROOM
LAB
EQUIP REP
SHOP
PREPARATION ROOM STORAGE
STG
DARK ROOM
LABORATORIES
LAB
LAB
Up
JAN
COMP CT TRAN
LAB
LAB
M.G. ROOM
Elev
Up
W
M
ELECTRICAL EQUIPMENT
MECHANICAL EQUIPMENT
Areaway
AIR CONDITIONING MACHINE ROOM
NORTH
0
10
FEET
50

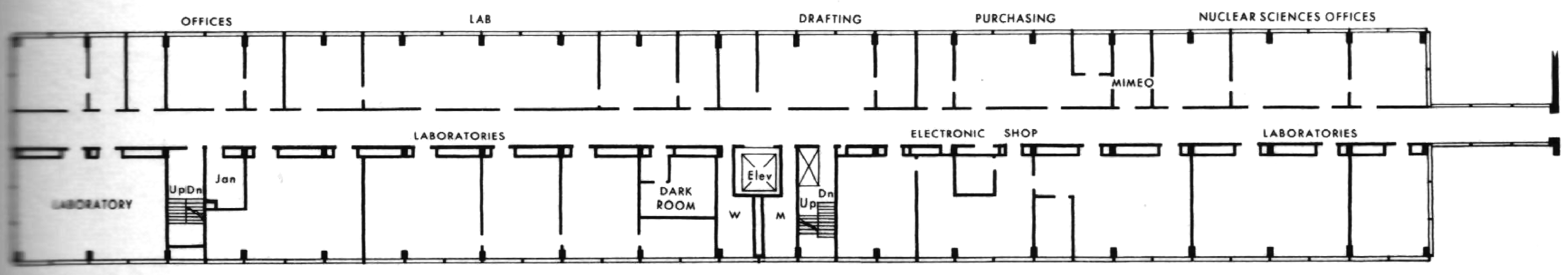
BASEMENT PLAN



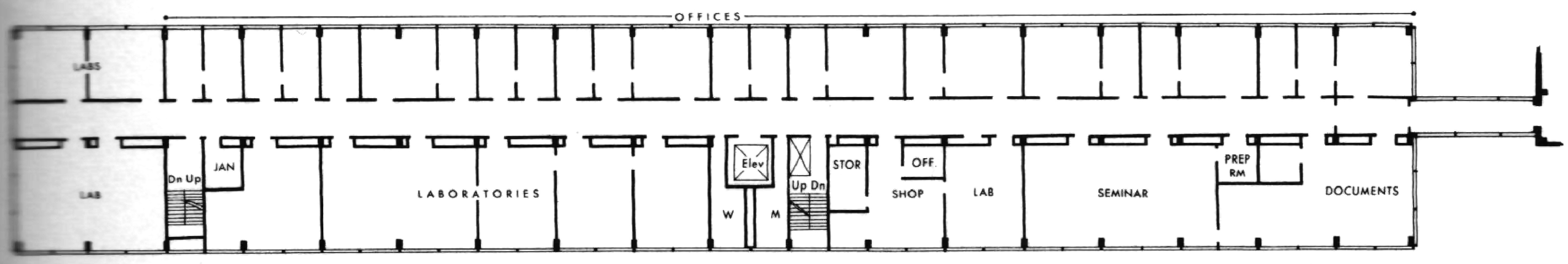
View of east side of the building showing glazed curtain wall.


MECH
Dn
RESEARCH LABORATORY
MECHANICAL EQUIPMENT
Elev
Dn
ROOF

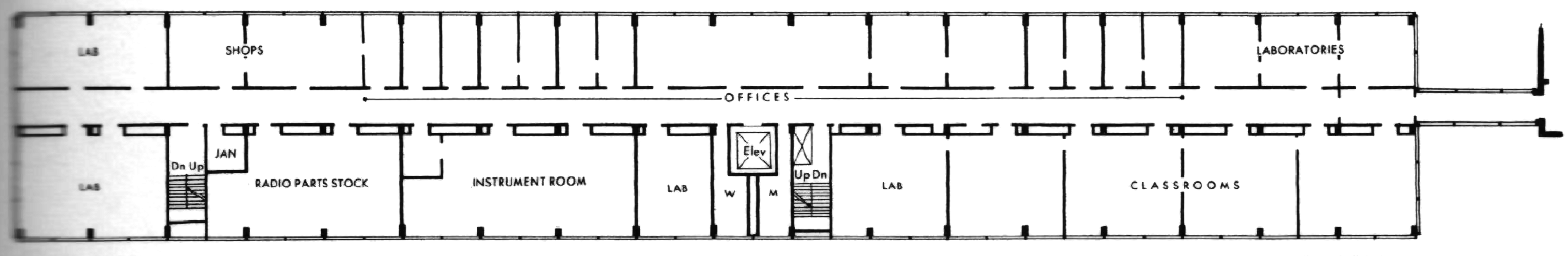
PENTHOUSE PLAN


OFFICES
LAB
DRAFTING
PURCHASING
NUCLEAR SCIENCES OFFICES
MIMEO
LABORATORIES
ELECTRONIC SHOP
LABORATORIES
LABORATORY
Up Dn
Jan
DARK ROOM
Elev
W
M
Up
Dn

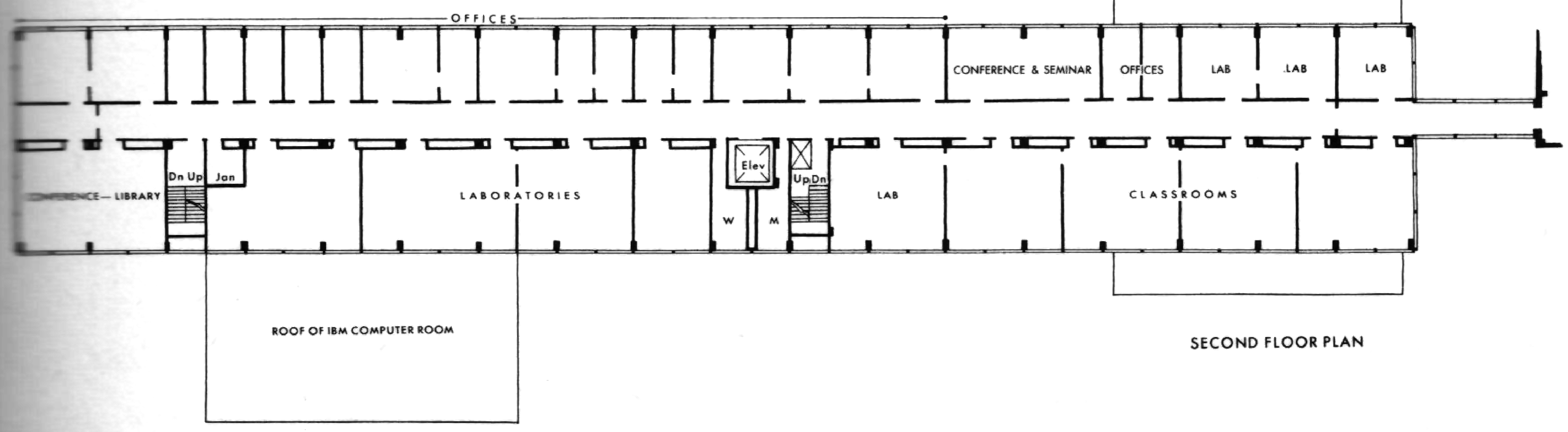
FIFTH FLOOR PLAN


OFFICES
LABS
LAB
Dn Up
JAN
LABORATORIES
Elev
W
M
Up Dn
STOR
OFF
SHOP
LAB
SEMINAR
PREP RM
DOCUMENTS

FOURTH FLOOR PLAN


LAB
SHOPS
LABORATORIES
OFFICES
LAB
Dn Up
JAN
RADIO PARTS STOCK
INSTRUMENT ROOM
LAB
Elev
W
M
Up Dn
LAB
CLASSROOMS

THIRD FLOOR PLAN


OFFICES
CONFERENCE & SEMINAR
OFFICES
LAB
LAB
LAB
CONFERENCE—LIBRARY
Dn Up
Jan
LABORATORIES
Elev
W
M
Up Dn
LAB
CLASSROOMS
ROOF OF IBM COMPUTER ROOM

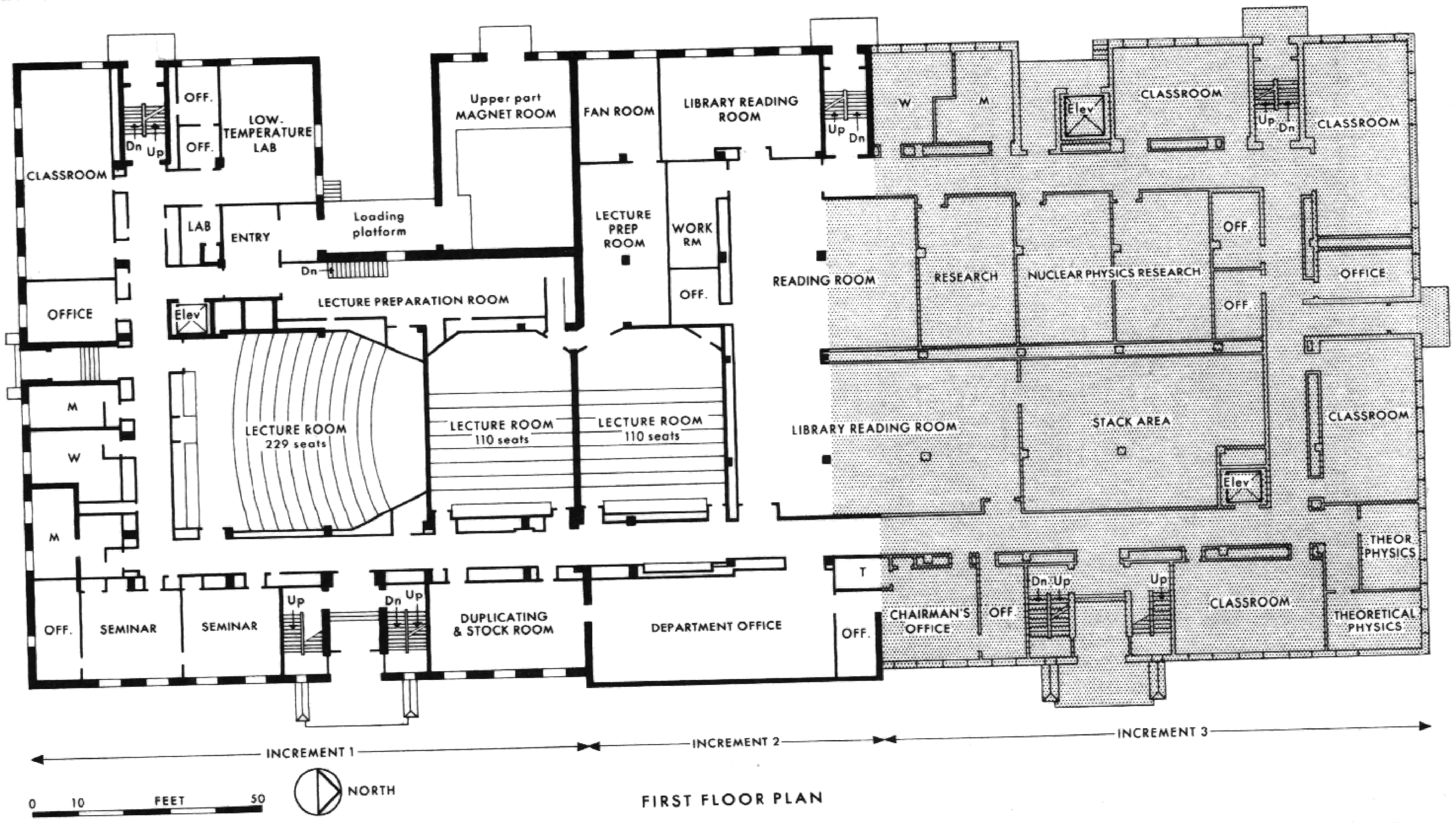
SECOND FLOOR PLAN

10.

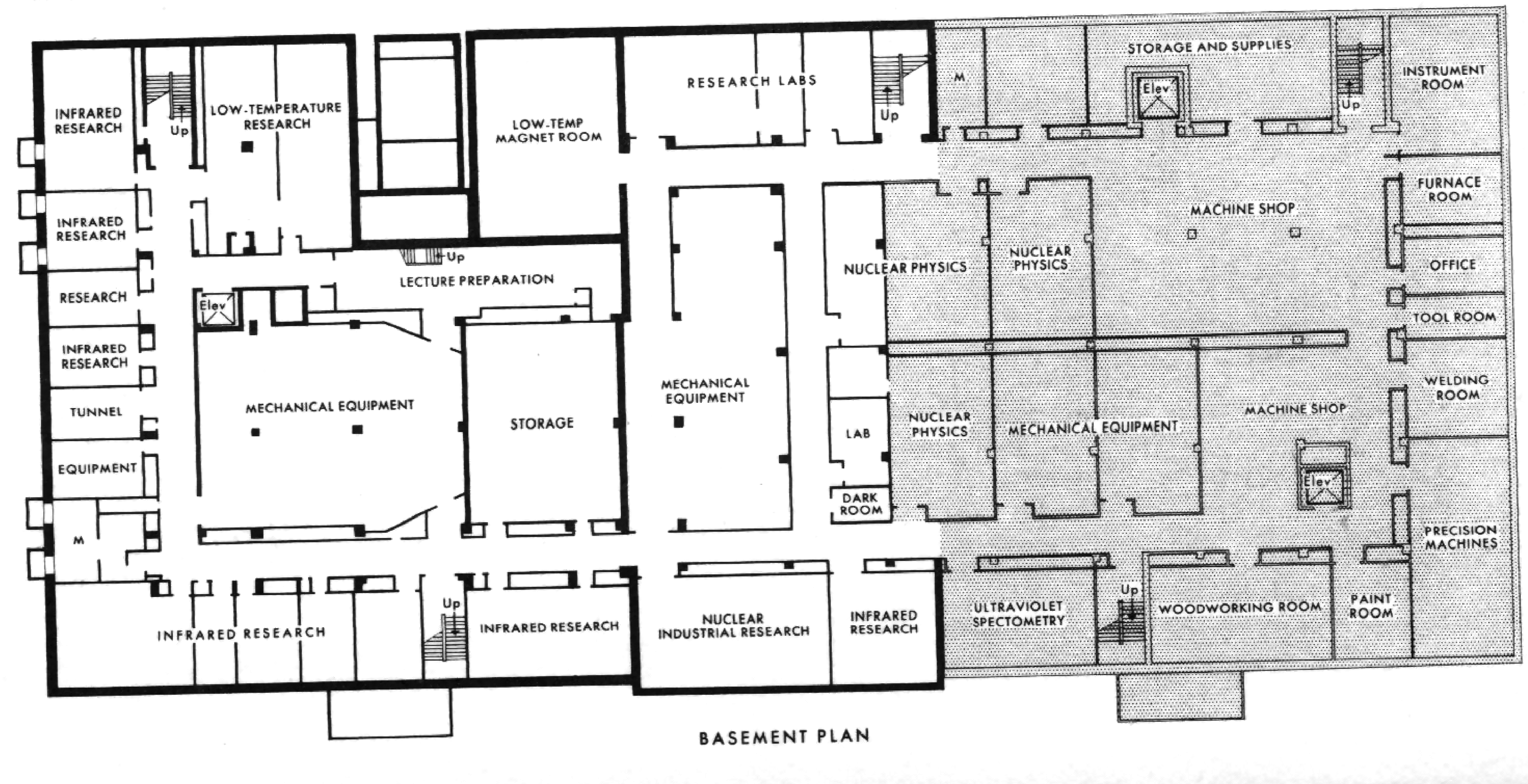
Physics Building
Ohio State University
Columbus, Ohio

Architects:	Tully and Hobbs Columbus, Ohio William E. Linch Ohio State University Architect
Completed: (1st and 2nd Section)	1st section —1951 2nd section—1959
Proposed Completion: (3rd Section)	3rd section —1966
Gross Area of Building:	1st section —85,000 sq. ft. 2nd section—45,000 sq. ft. 3rd section —80,000 sq. ft. Total: 210,000 sq. ft.
Total Cost of Building:	1st section —$1,100,000 2nd section— 1,200,000 3rd section — 2,600,000 Total: $4,900,000*
Air Conditioning:	Water is chilled in basement, circulated thru coils in ducts on various floors to cool auditorium and central core of research rooms, as well as proposed library in 3rd section.

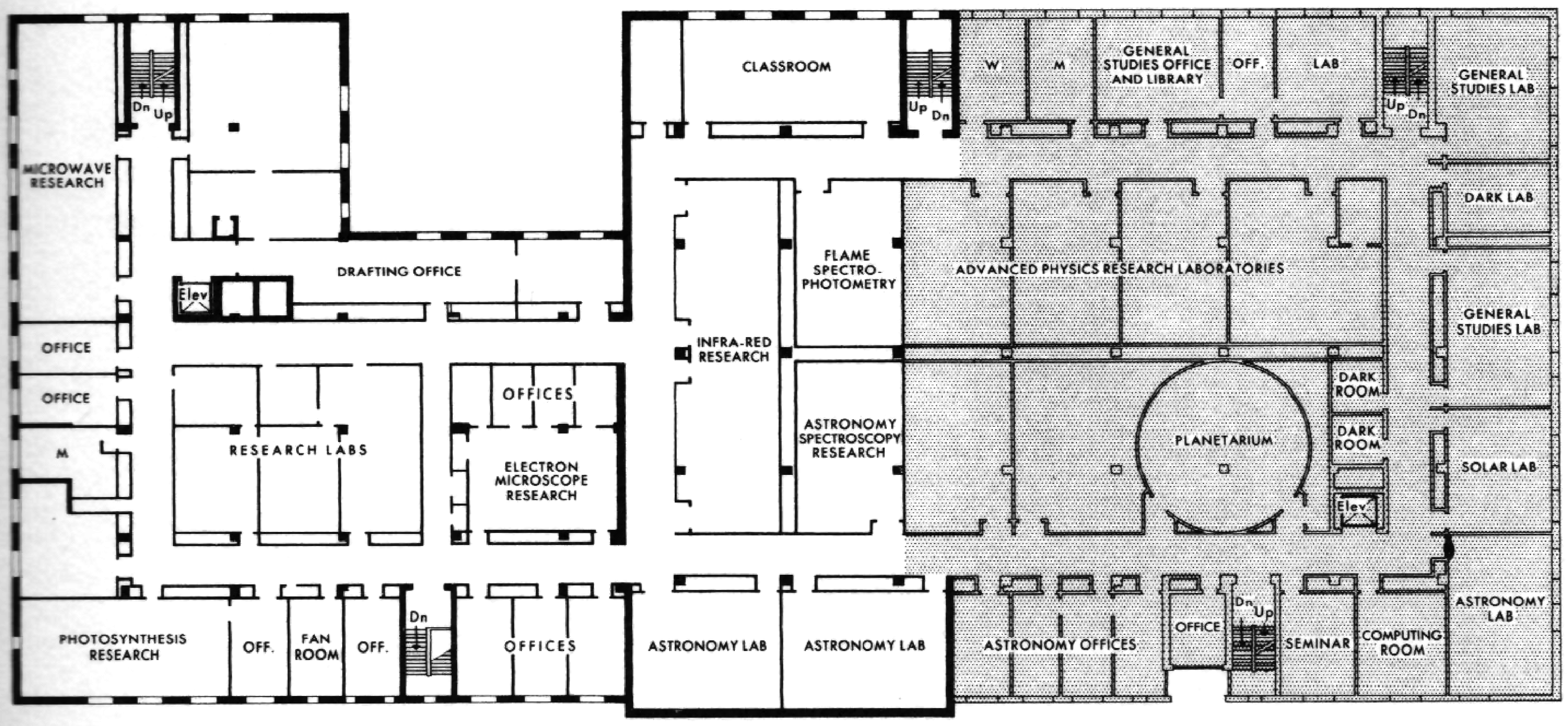
* Includes heating, ventilating, partial air conditioning, electrical and mechanical services, and laboratory furniture.


CLASSROOM
OFFICE
M
W
M
OFF.
SEMINAR
SEMINAR
OFF.
LOW-TEMPERATURE LAB
Dn Up
LAB
ENTRY
Loading platform
Dn
Elev
LECTURE PREPARATION ROOM
LECTURE ROOM 229 seats
LECTURE ROOM 110 seats
LECTURE ROOM 110 seats
Up
Dn Up
DUPLICATING & STOCK ROOM
Upper part MAGNET ROOM
FAN ROOM
LIBRARY READING ROOM
LECTURE PREP ROOM
WORK RM
OFF.
READING ROOM
LIBRARY READING ROOM
DEPARTMENT OFFICE
T
OFF.
CHAIRMAN'S OFFICE
W
M
CLASSROOM
CLASSROOM
RESEARCH
NUCLEAR PHYSICS RESEARCH
OFF
OFFICE
STACK AREA
CLASSROOM
THEOR PHYSICS
THEORETICAL PHYSICS
CLASSROOM
INCREMENT 1
INCREMENT 2
INCREMENT 3
0 10 FEET 50
NORTH

FIRST FLOOR PLAN

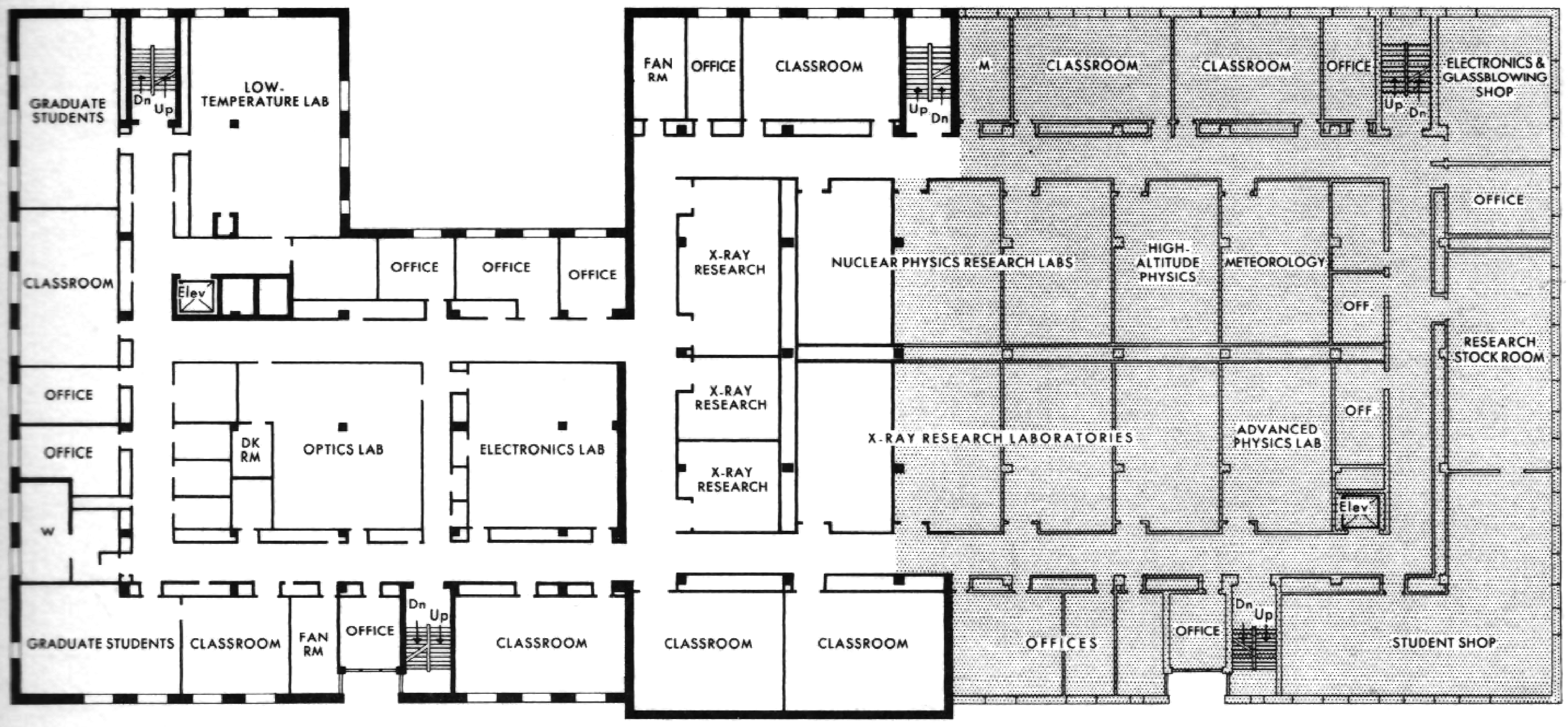

INFRARED RESEARCH
INFRARED RESEARCH
RESEARCH
INFRARED RESEARCH
TUNNEL
EQUIPMENT
M
LOW-TEMPERATURE RESEARCH
Up
Elev
LECTURE PREPARATION
MECHANICAL EQUIPMENT
STORAGE
LOW-TEMP MAGNET ROOM
RESEARCH LABS
MECHANICAL EQUIPMENT
NUCLEAR PHYSICS
LAB
DARK ROOM
INFRARED RESEARCH
INFRARED RESEARCH
NUCLEAR INDUSTRIAL RESEARCH
INFRARED RESEARCH
STORAGE AND SUPPLIES
M
INSTRUMENT ROOM
NUCLEAR PHYSICS
MACHINE SHOP
FURNACE ROOM
OFFICE
TOOL ROOM
NUCLEAR PHYSICS
MECHANICAL EQUIPMENT
MACHINE SHOP
WELDING ROOM
PRECISION MACHINES
ULTRAVIOLET SPECTOMETRY
WOODWORKING ROOM
PAINT ROOM

BASEMENT PLAN

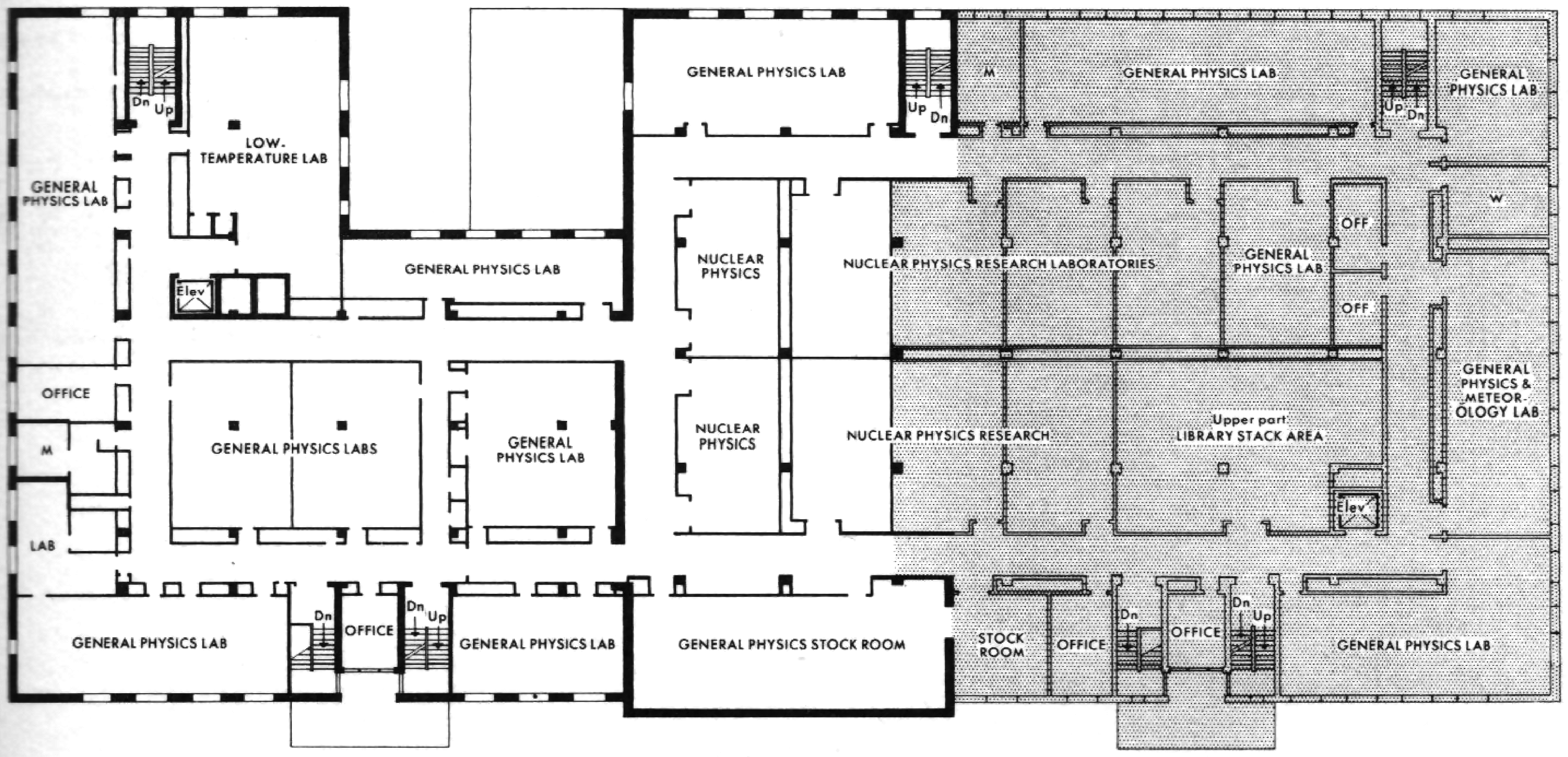

MICROWAVE RESEARCH
Dn
Up
CLASSROOM
Up
Dn
W
M
GENERAL STUDIES OFFICE AND LIBRARY
OFF.
LAB
Up
Dn
GENERAL STUDIES LAB
DRAFTING OFFICE
Elev
FLAME SPECTRO-PHOTOMETRY
ADVANCED PHYSICS RESEARCH LABORATORIES
DARK LAB
INFRA-RED RESEARCH
GENERAL STUDIES LAB
OFFICE
OFFICE
OFFICES
DARK ROOM
DARK ROOM
M
RESEARCH LABS
ELECTRON MICROSCOPE RESEARCH
ASTRONOMY SPECTROSCOPY RESEARCH
PLANETARIUM
SOLAR LAB
Elev
PHOTOSYNTHESIS RESEARCH
OFF.
FAN ROOM
OFF.
Dn
OFFICES
ASTRONOMY LAB
ASTRONOMY LAB
ASTRONOMY OFFICES
OFFICE
Dn
Up
SEMINAR
COMPUTING ROOM
ASTRONOMY LAB

FOURTH FLOOR PLAN

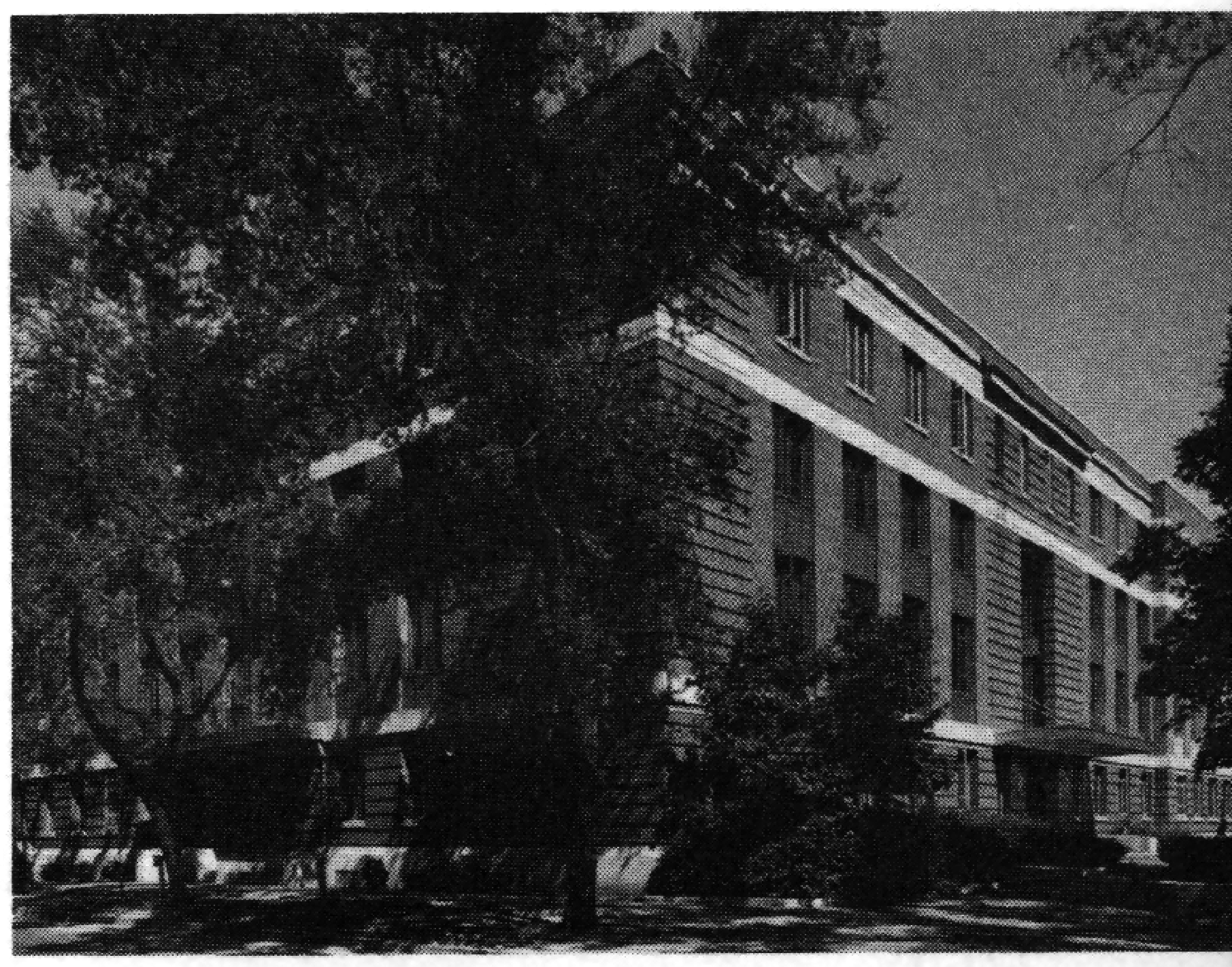
Photographs below show one of the principal entrances and northeast corner of the original building with extension at far right.


GRADUATE STUDENTS
Dn
Up
LOW-TEMPERATURE LAB
FAN RM
OFFICE
CLASSROOM
Up
Dn
M
CLASSROOM
CLASSROOM
OFFICE
Up
Dn
ELECTRONICS & GLASSBLOWING SHOP
OFFICE
CLASSROOM
Elev
OFFICE
OFFICE
OFFICE
X-RAY RESEARCH
NUCLEAR PHYSICS RESEARCH LABS
HIGH-ALTITUDE PHYSICS
METEOROLOGY
OFF.
RESEARCH STOCK ROOM
OFFICE
OFFICE
DK RM
OPTICS LAB
ELECTRONICS LAB
X-RAY RESEARCH
X-RAY RESEARCH LABORATORIES
ADVANCED PHYSICS LAB
OFF.
X-RAY RESEARCH
W
Elev
GRADUATE STUDENTS
CLASSROOM
FAN RM
OFFICE
Dn
Up
CLASSROOM
CLASSROOM
CLASSROOM
OFFICES
OFFICE
Dn
Up
STUDENT SHOP

THIRD FLOOR PLAN


Dn
Up
LOW-TEMPERATURE LAB
GENERAL PHYSICS LAB
Up
Dn
M
GENERAL PHYSICS LAB
Up
Dn
GENERAL PHYSICS LAB
GENERAL PHYSICS LAB
Elev
GENERAL PHYSICS LAB
NUCLEAR PHYSICS
NUCLEAR PHYSICS RESEARCH LABORATORIES
OFF
GENERAL PHYSICS LAB
OFF
W
OFFICE
M
GENERAL PHYSICS LABS
GENERAL PHYSICS LAB
NUCLEAR PHYSICS
NUCLEAR PHYSICS RESEARCH
Upper part LIBRARY STACK AREA
GENERAL PHYSICS & METEOR-OLOGY LAB
Elev
LAB
GENERAL PHYSICS LAB
Dn
OFFICE
Dn
Up
GENERAL PHYSICS LAB
GENERAL PHYSICS STOCK ROOM
STOCK ROOM
OFFICE
Dn
OFFICE
Dn
Up
GENERAL PHYSICS LAB

SECOND FLOOR PLAN

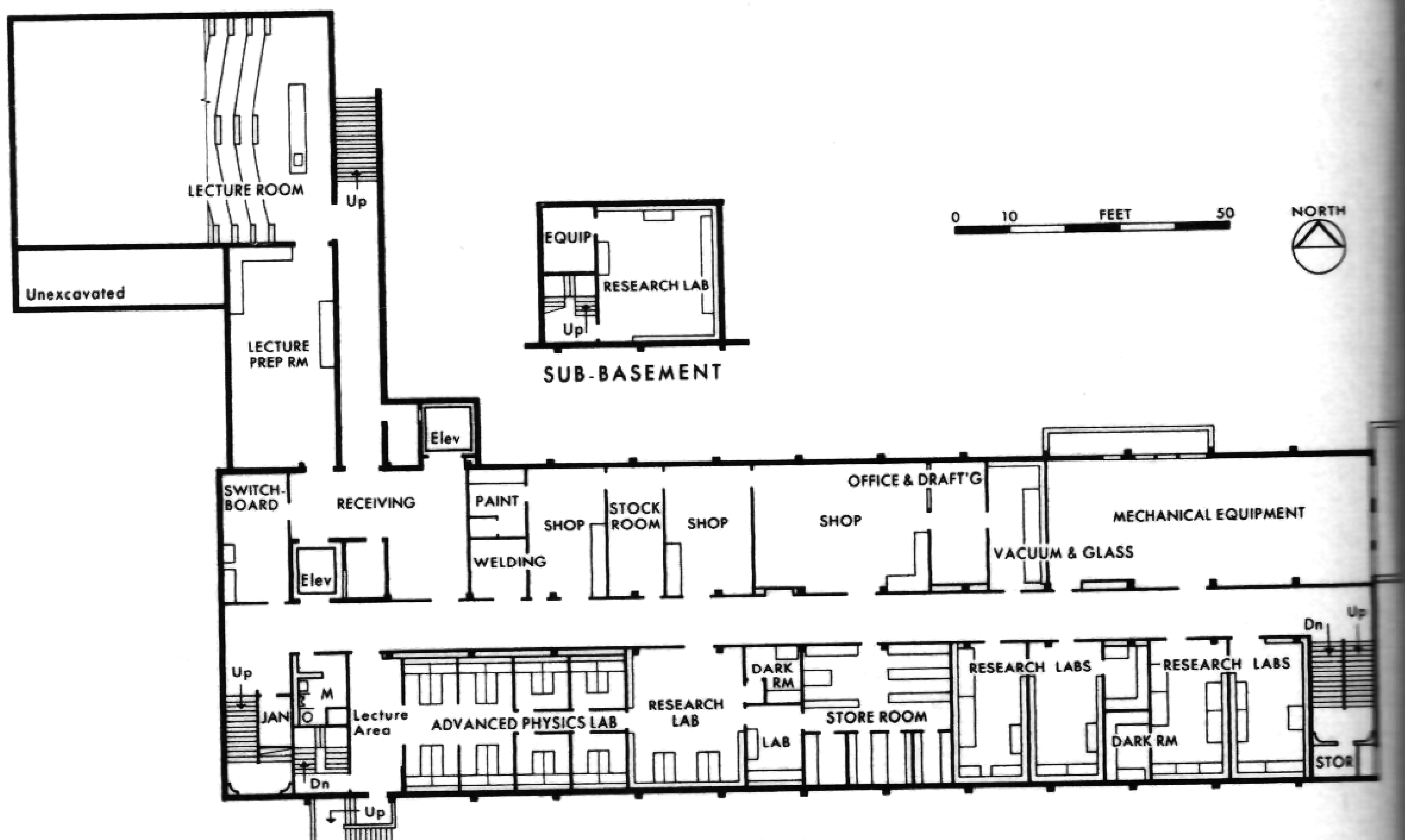


11.

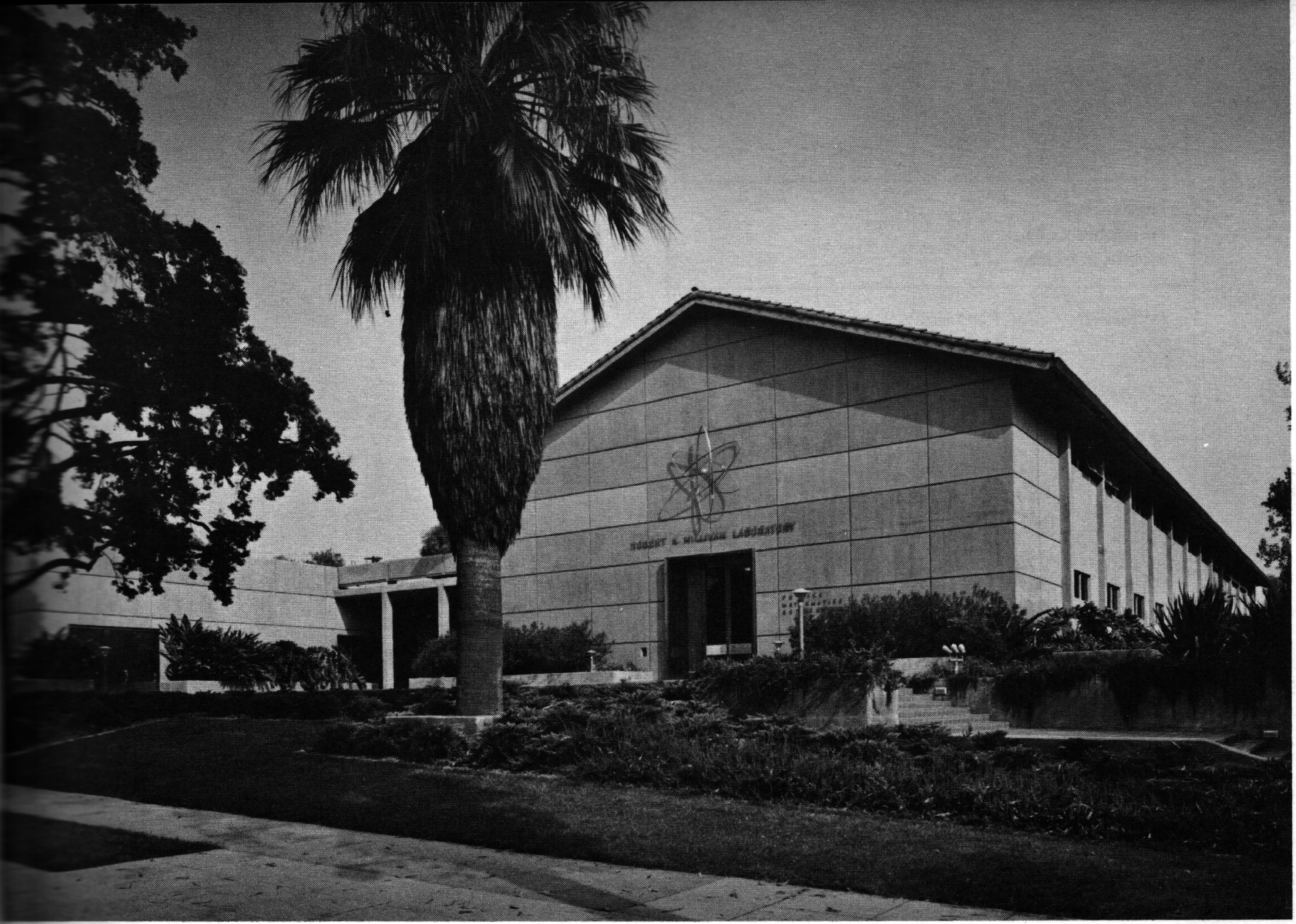
Robert A. Millikan Laboratory
Pomona College
Claremont, California

Architects:	Smith, Powell and Morgridge Los Angeles, California
Completed:	November 1958
Gross Area of Building:	43,174 sq. ft.
Total Cost of Building:	$949,600*
Air Conditioning:	Freon — 12 refrigeration cycle with evaporative condenser, reciprocating compressor, Dx cooling coils, dual duct air supply. Building has continuous forced air ventilation with 30% minimum outside air. Lecture room has independent forced air supply with positive return exhaust air system, 6000 cfm.

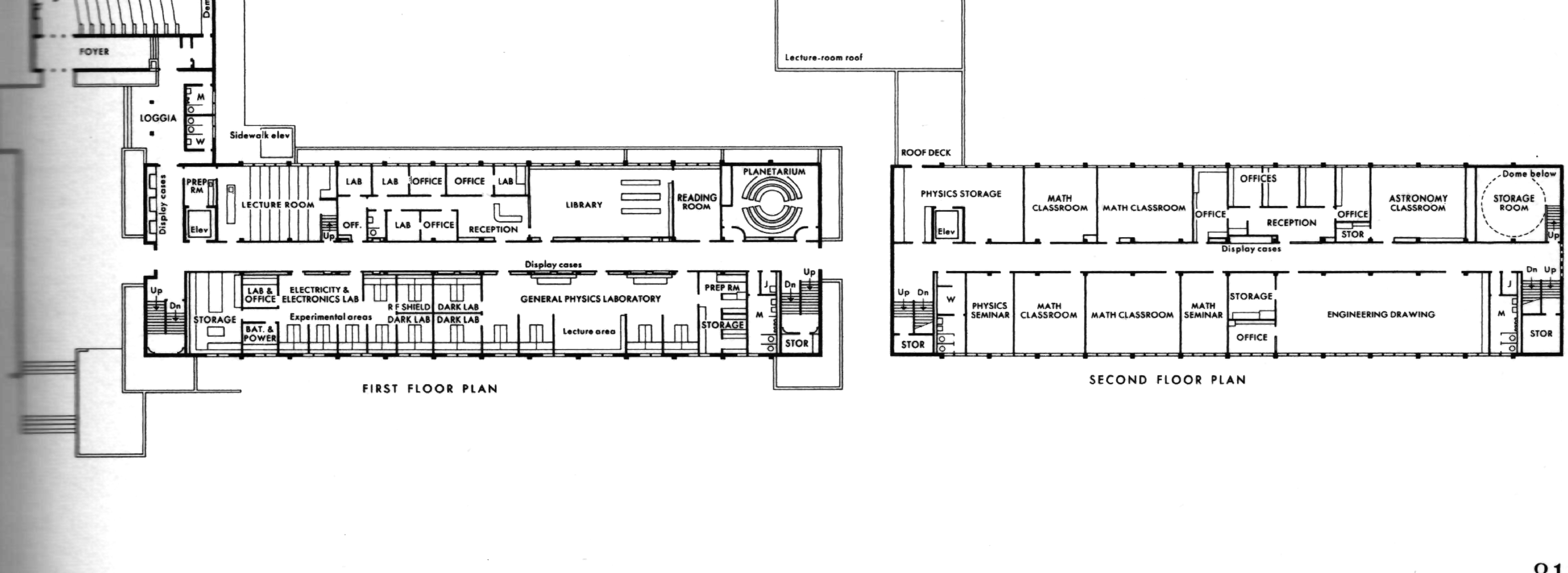
* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.


LECTURE ROOM
Up
Unexcavated
LECTURE PREP RM
EQUIP
RESEARCH LAB
Up
SUB-BASEMENT
0 10 FEET 50
NORTH
Elev
SWITCH-BOARD
RECEIVING
Elev
PAINT
WELDING
SHOP
STOCK ROOM
SHOP
SHOP
OFFICE & DRAFT'G
VACUUM & GLASS
MECHANICAL EQUIPMENT
Up
JAN
M
Lecture Area
Dn
Up
ADVANCED PHYSICS LAB
RESEARCH LAB
DARK RM
LAB
STORE ROOM
RESEARCH LABS
RESEARCH LABS
DARK RM
Dn
Up
STOR

BASEMENT FLOOR PLAN



Main entrance. Lecture room is in a separate wing entered through arcade at left, permitting independent use.


LECTURE ROOM
140 seats
Demonstration bridge
Dn
FOYER
LOGGIA
M
W
Sidewalk elev
Display cases
PREP RM
Elev
LECTURE ROOM
Up
LAB
LAB
OFFICE
OFFICE
LAB
OFF.
LAB
OFFICE
RECEPTION
LIBRARY
READING ROOM
PLANETARIUM
Display cases
Up
Dn
STORAGE
LAB & OFFICE
BAT. & POWER
ELECTRICITY & ELECTRONICS LAB
Experimental areas
R F SHIELD
DARK LAB
DARK LAB
DARK LAB
GENERAL PHYSICS LABORATORY
Lecture area
PREP RM
STORAGE
J
M
Dn
Up
STOR

FIRST FLOOR PLAN

Lecture-room roof
ROOF DECK
PHYSICS STORAGE
Elev
MATH CLASSROOM
MATH CLASSROOM
OFFICES
OFFICE
RECEPTION
OFFICE
STOR
ASTRONOMY CLASSROOM
Dome below
STORAGE ROOM
Up
Display cases
Up
Dn
STOR
W
PHYSICS SEMINAR
MATH CLASSROOM
MATH CLASSROOM
MATH SEMINAR
STORAGE
OFFICE
ENGINEERING DRAWING
J
M
Dn
Up
STOR

SECOND FLOOR PLAN

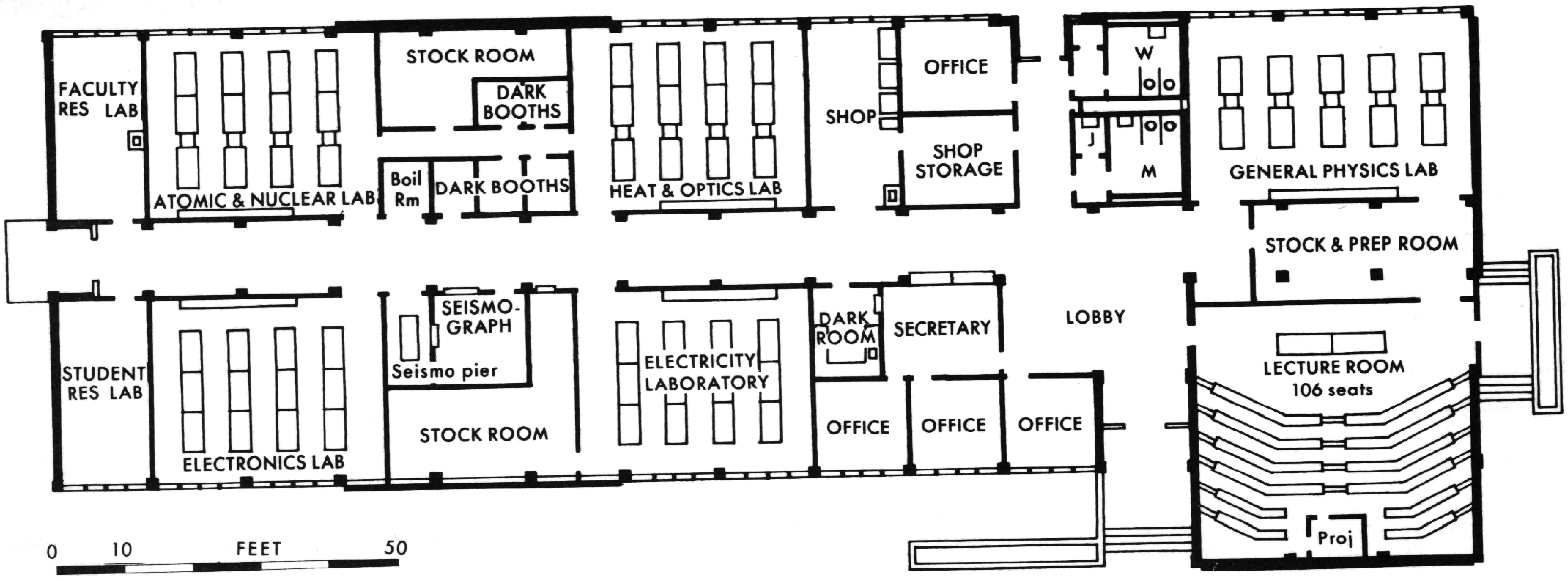
12.

Physics Hall
Spring Hill College
Mobile, Alabama

Architects:	Platt Roberts and Company Mobile, Alabama
Completed:	May 25, 1959
Gross Area of Building:	14,200 sq. ft.
Total Cost of Building:	$200,000*
Air Conditioning:	Three units of 7½, 10 and 15 h.p. They all use water cooling tower located on top of the building.

* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.

One-story physics building is the smallest example in this book. Offices, entrance, and lecture room are at right.


FACULTY RES LAB
ATOMIC & NUCLEAR LAB
STOCK ROOM
DARK BOOTHS
Boil Rm
DARK BOOTHS
HEAT & OPTICS LAB
SHOP
OFFICE
SHOP STORAGE
W
J
M
GENERAL PHYSICS LAB
STOCK & PREP ROOM
STUDENT RES LAB
ELECTRONICS LAB
SEISMO-GRAPH
Seismo pier
STOCK ROOM
ELECTRICITY LABORATORY
DARK ROOM
SECRETARY
LOBBY
OFFICE
OFFICE
OFFICE
LECTURE ROOM 106 seats
Proj
0
10
FEET
50

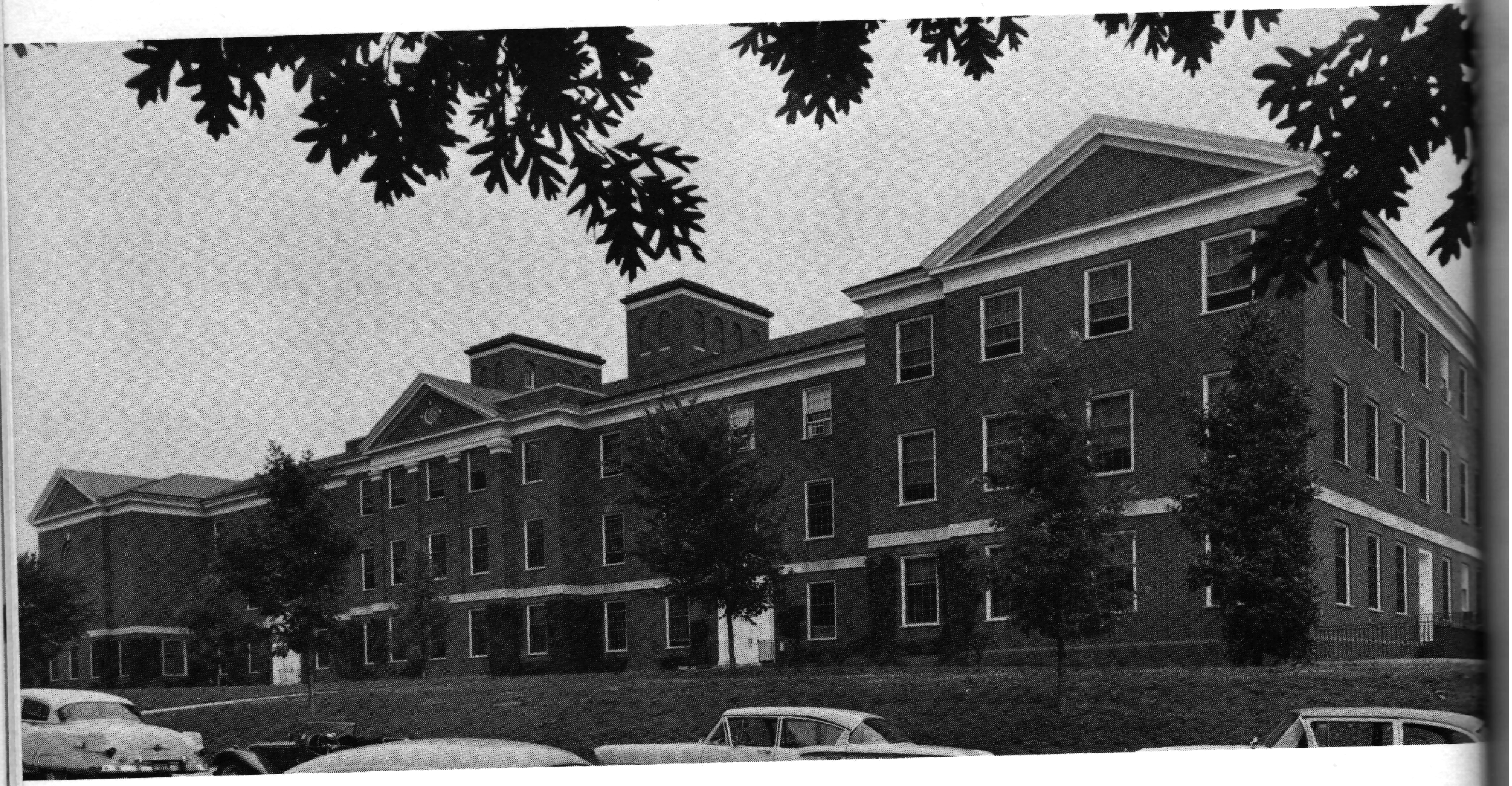
13.

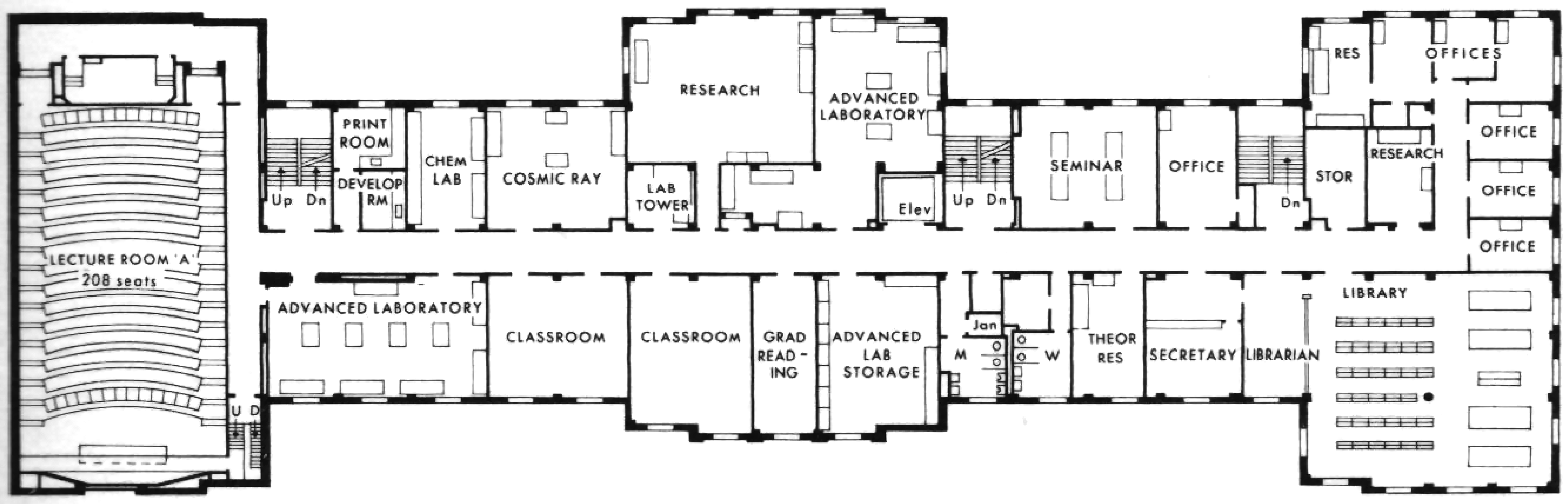
Physics Laboratory
University of Virginia
Charlottesville, Virginia

Architects:	Eggers and Higgins New York City, New York
Completed:	May 1954
Gross Area of Building:	90,000 sq. ft.
Total Cost of Building:	Between $1,500,000 and 1,750,000*
Air Conditioning:	None

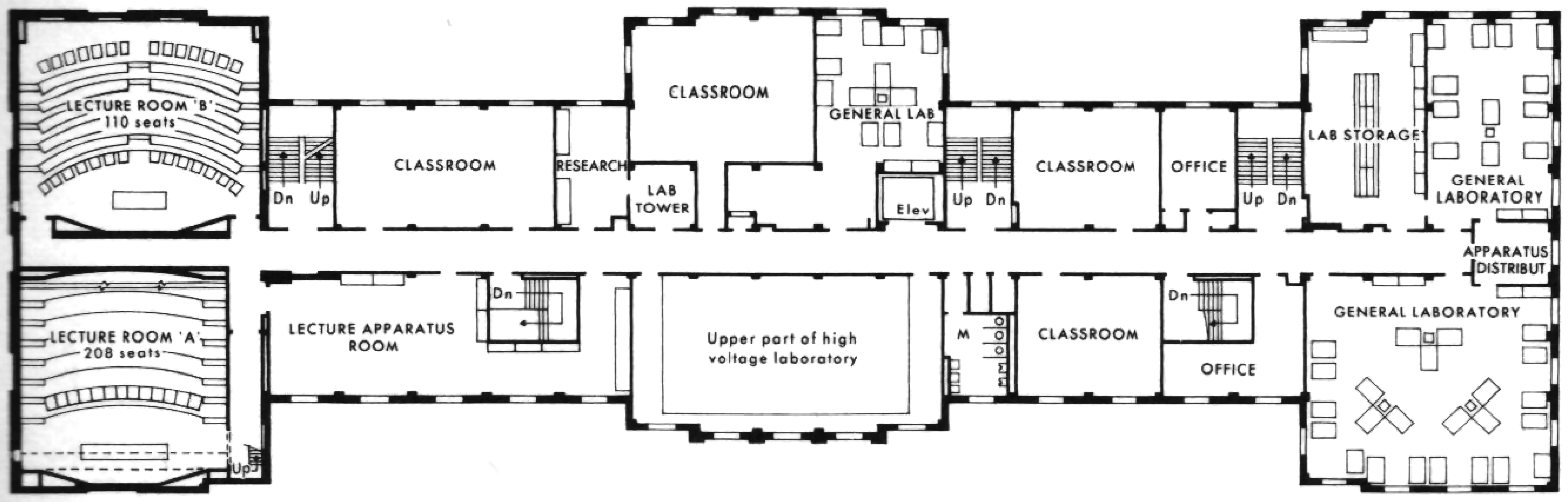
* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

View of building from the southeast.

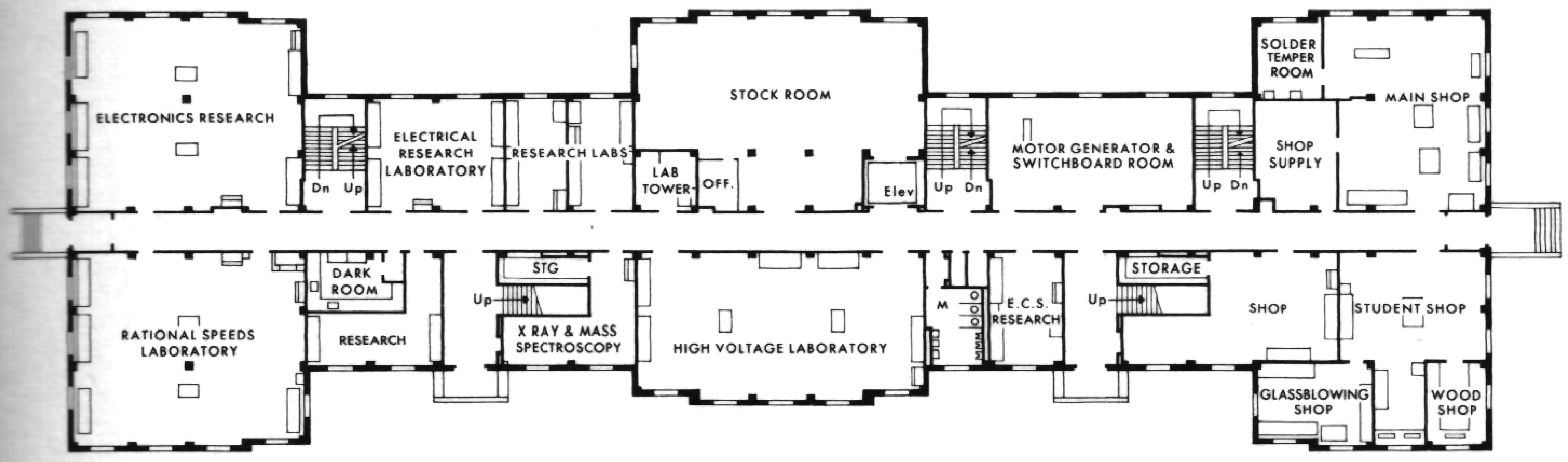



LECTURE ROOM 'A' 208 seats
Up
Dn
PRINT ROOM
DEVELOP RM
CHEM LAB
COSMIC RAY
RESEARCH
LAB TOWER
ADVANCED LABORATORY
Elev
Up
Dn
SEMINAR
OFFICE
Dn
RES
OFFICES
STOR
RESEARCH
OFFICE
OFFICE
OFFICE
ADVANCED LABORATORY
CLASSROOM
CLASSROOM
GRAD READ-ING
ADVANCED LAB STORAGE
Jan
M
W
THEOR RES
SECRETARY
LIBRARIAN
LIBRARY
U D

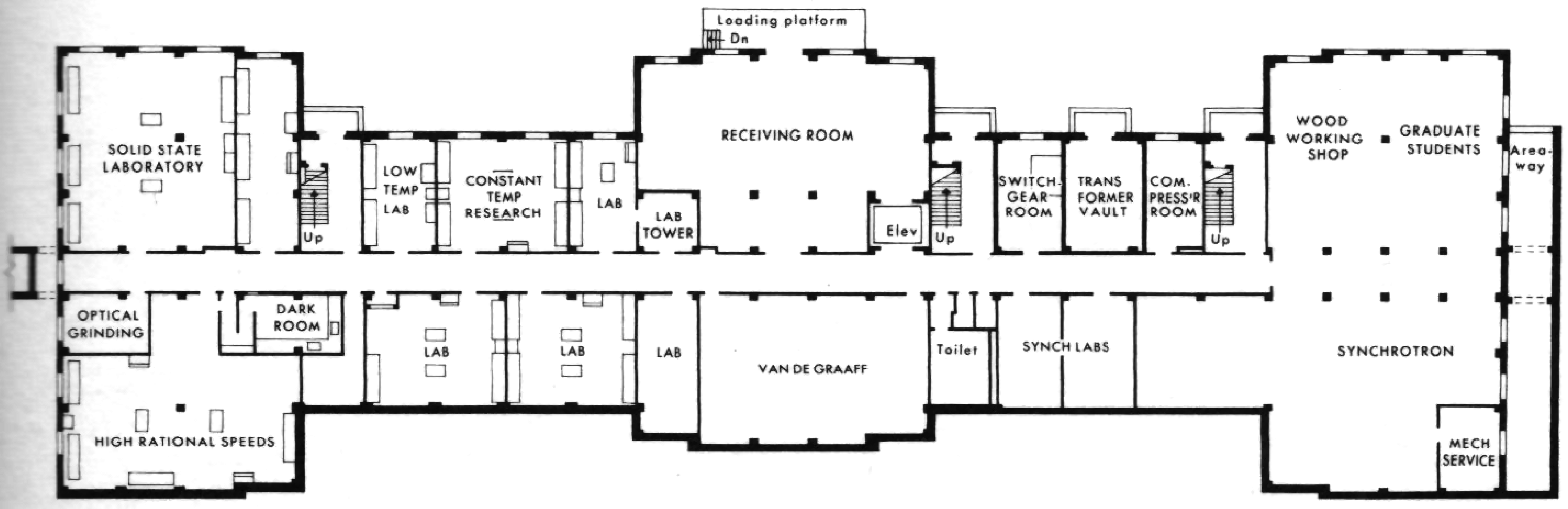
THIRD FLOOR PLAN


LECTURE ROOM 'B' 110 seats
LECTURE ROOM 'A' 208 seats
Up
Dn
Up
CLASSROOM
RESEARCH
CLASSROOM
LAB TOWER
GENERAL LAB
Elev
Up
Dn
CLASSROOM
OFFICE
Up
Dn
LAB STORAGE
GENERAL LABORATORY
APPARATUS DISTRIBUT.
LECTURE APPARATUS ROOM
Dn
Upper part of high voltage laboratory
M
CLASSROOM
Dn
OFFICE
GENERAL LABORATORY

SECOND FLOOR PLAN


ELECTRONICS RESEARCH
Dn
Up
ELECTRICAL RESEARCH LABORATORY
RESEARCH LABS
STOCK ROOM
LAB TOWER
OFF.
Elev
Up
Dn
MOTOR GENERATOR & SWITCHBOARD ROOM
Up
Dn
SOLDER TEMPER ROOM
SHOP SUPPLY
MAIN SHOP
RATIONAL SPEEDS LABORATORY
DARK ROOM
RESEARCH
STG
Up
X RAY & MASS SPECTROSCOPY
HIGH VOLTAGE LABORATORY
M
E.C.S. RESEARCH
Up
STORAGE
SHOP
STUDENT SHOP
GLASSBLOWING SHOP
WOOD SHOP

FIRST FLOOR PLAN


Loading platform
Dn
SOLID STATE LABORATORY
Up
LOW TEMP LAB
CONSTANT TEMP RESEARCH
LAB
RECEIVING ROOM
LAB TOWER
Elev
Up
SWITCH-GEAR ROOM
TRANS FORMER VAULT
COM-PRESS'R ROOM
Up
WOOD WORKING SHOP
GRADUATE STUDENTS
Area-way
OPTICAL GRINDING
DARK ROOM
LAB
LAB
LAB
VAN DE GRAAFF
Toilet
SYNCH LABS
SYNCHROTRON
HIGH RATIONAL SPEEDS
MECH SERVICE

BASEMENT FLOOR PLAN

0 10 FEET 50

NORTH

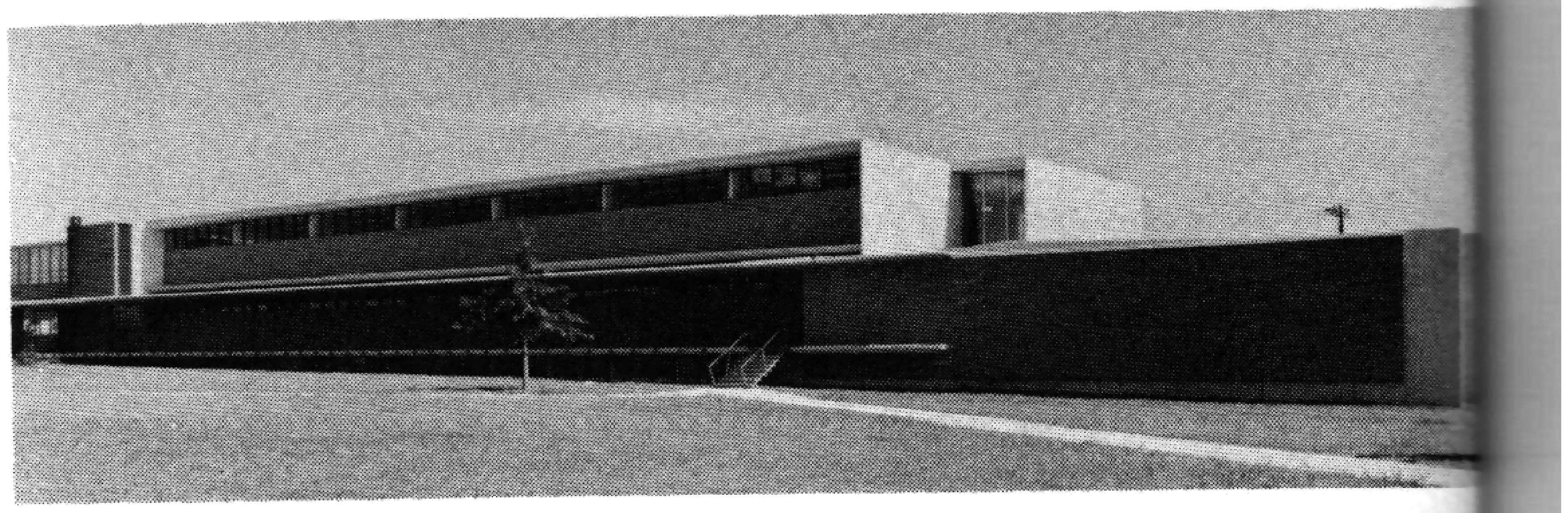
14.

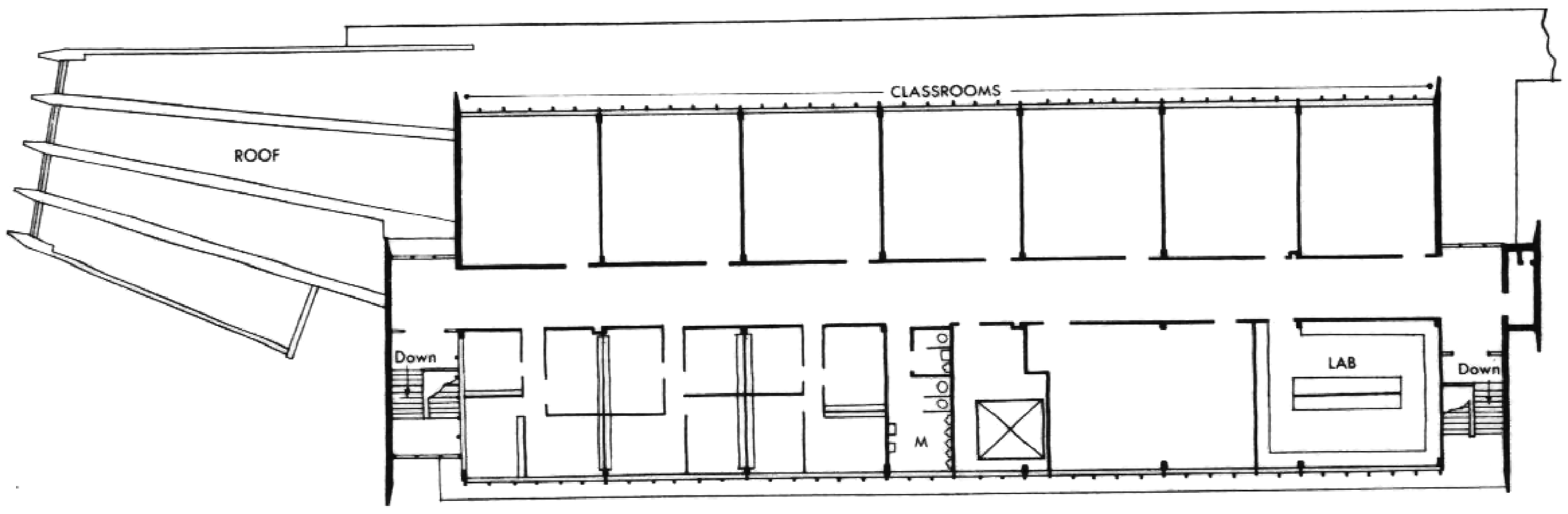
Mathematics and Physics Building
University of Wichita
Wichita, Kansas

Architects:	W. I. Fisher Wichita, Kansas
Completed:	August 1958
Gross Area of Building:	40,780 sq. ft.
Total Cost of Building:	$548,933*
Air Conditioning:	Dual duct, high velocity distribution from units on each floor; 125 ton compressor; 2.5 million Btu gas fired boiler.

* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.

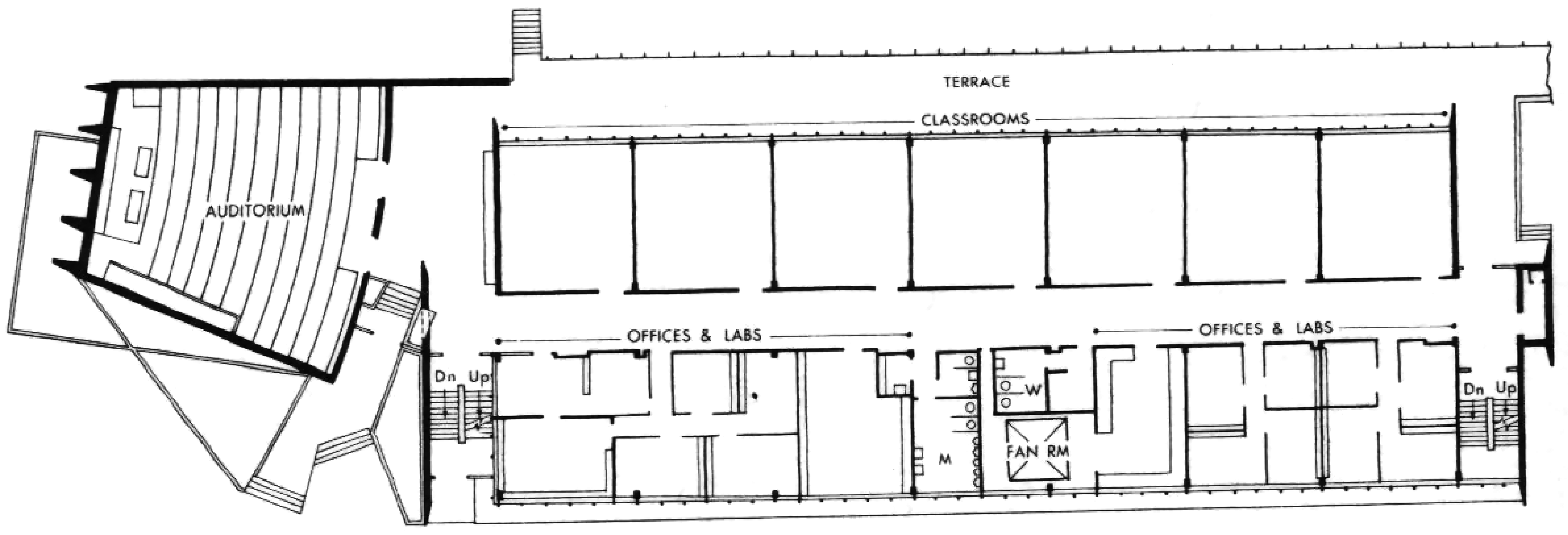
North side of building. Note high windows and useful interior wall space beneath.





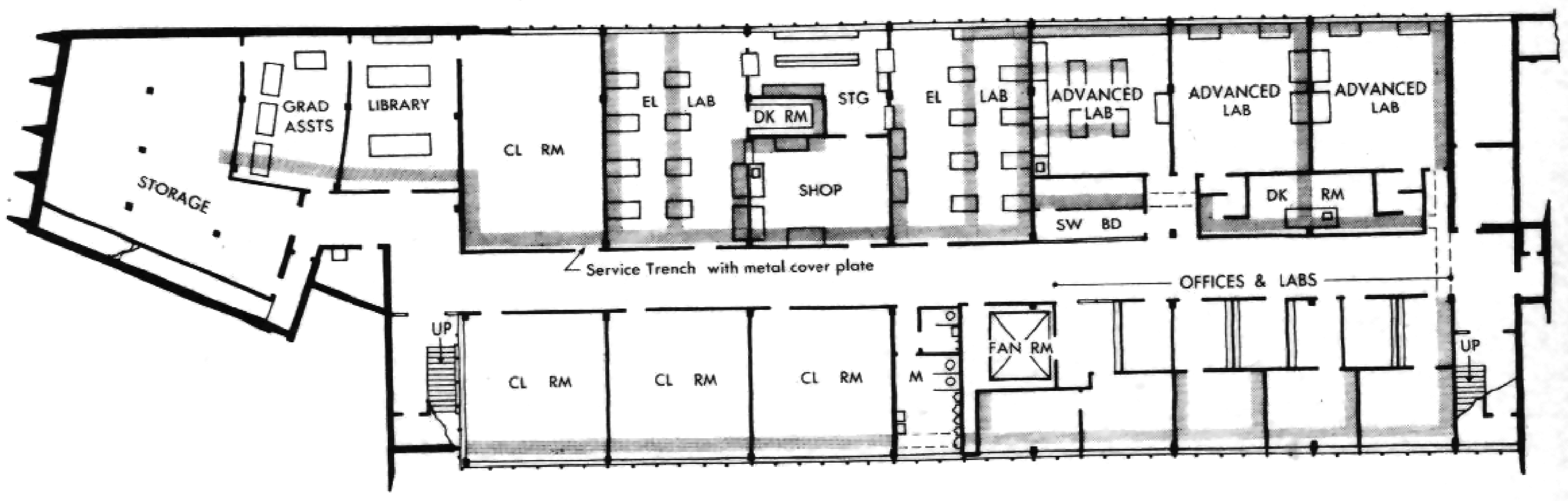
CLASSROOMS
ROOF
Down
LAB
Down
M

THIRD FLOOR PLAN



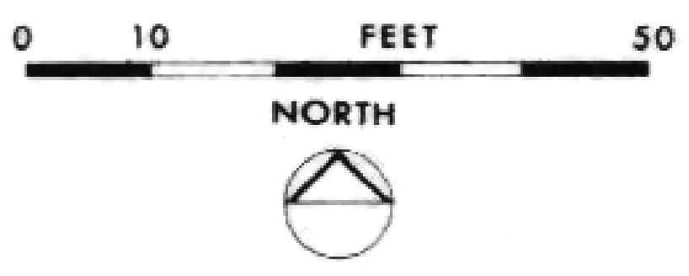
TERRACE
CLASSROOMS
AUDITORIUM
OFFICES & LABS
OFFICES & LABS
Dn Up
W
M
FAN RM
Dn Up

SECOND FLOOR PLAN

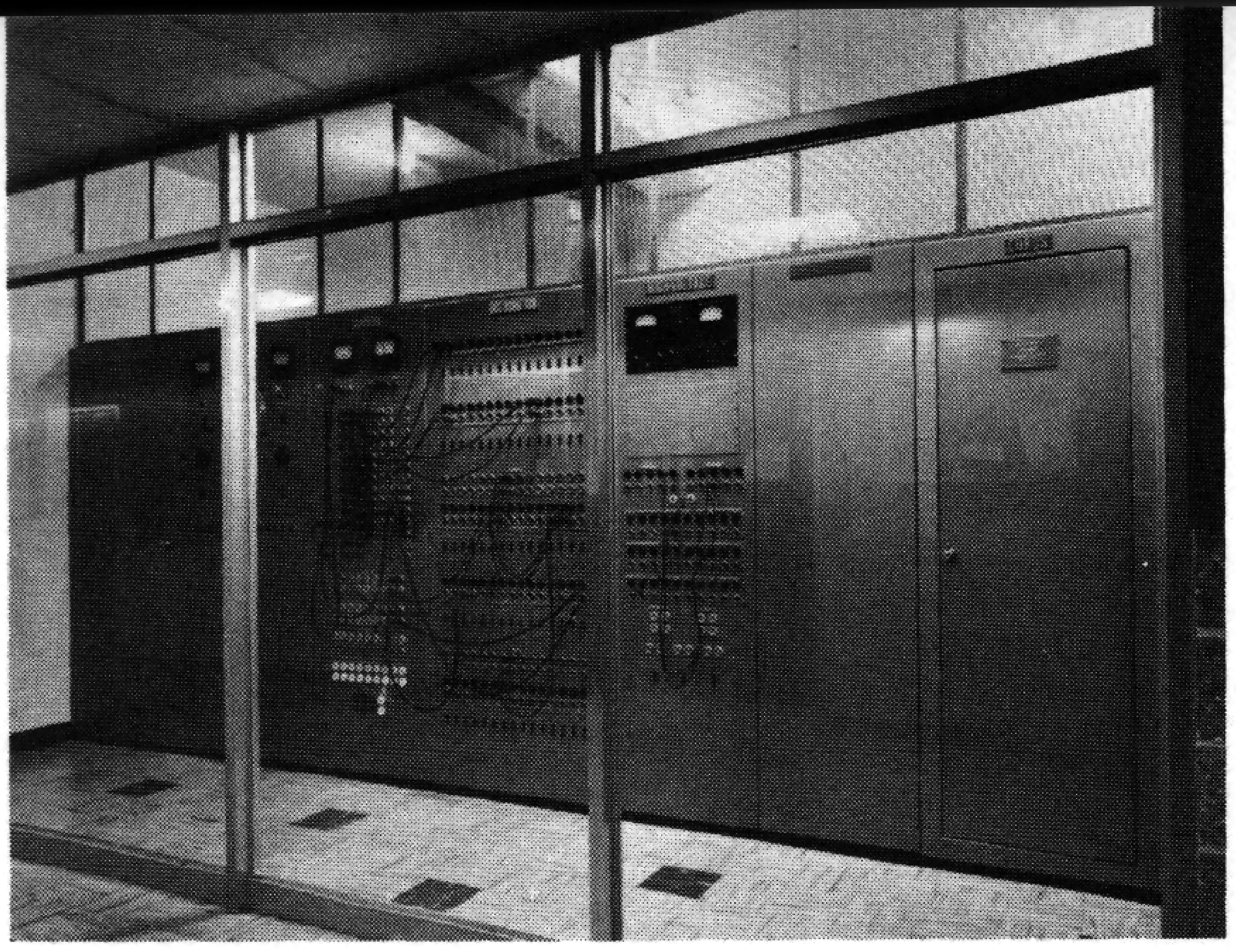


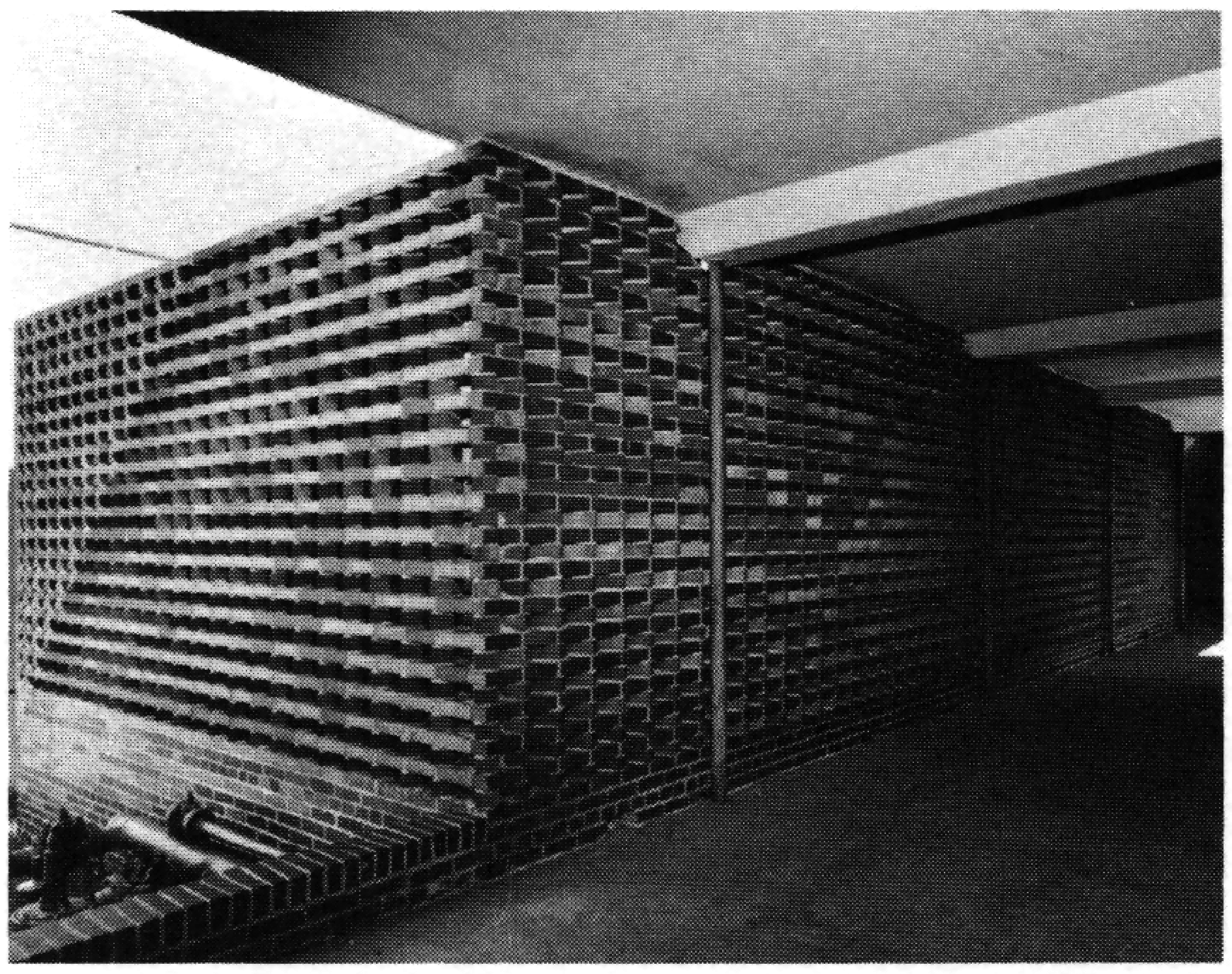
GRAD ASSTS
LIBRARY
STORAGE
CL RM
EL LAB
DK RM
STG
SHOP
EL LAB
ADVANCED LAB
ADVANCED LAB
ADVANCED LAB
DK RM
SW BD
Service Trench with metal cover plate
OFFICES & LABS
UP
CL RM
CL RM
CL RM
M
FAN RM
UP

FIRST FLOOR PLAN

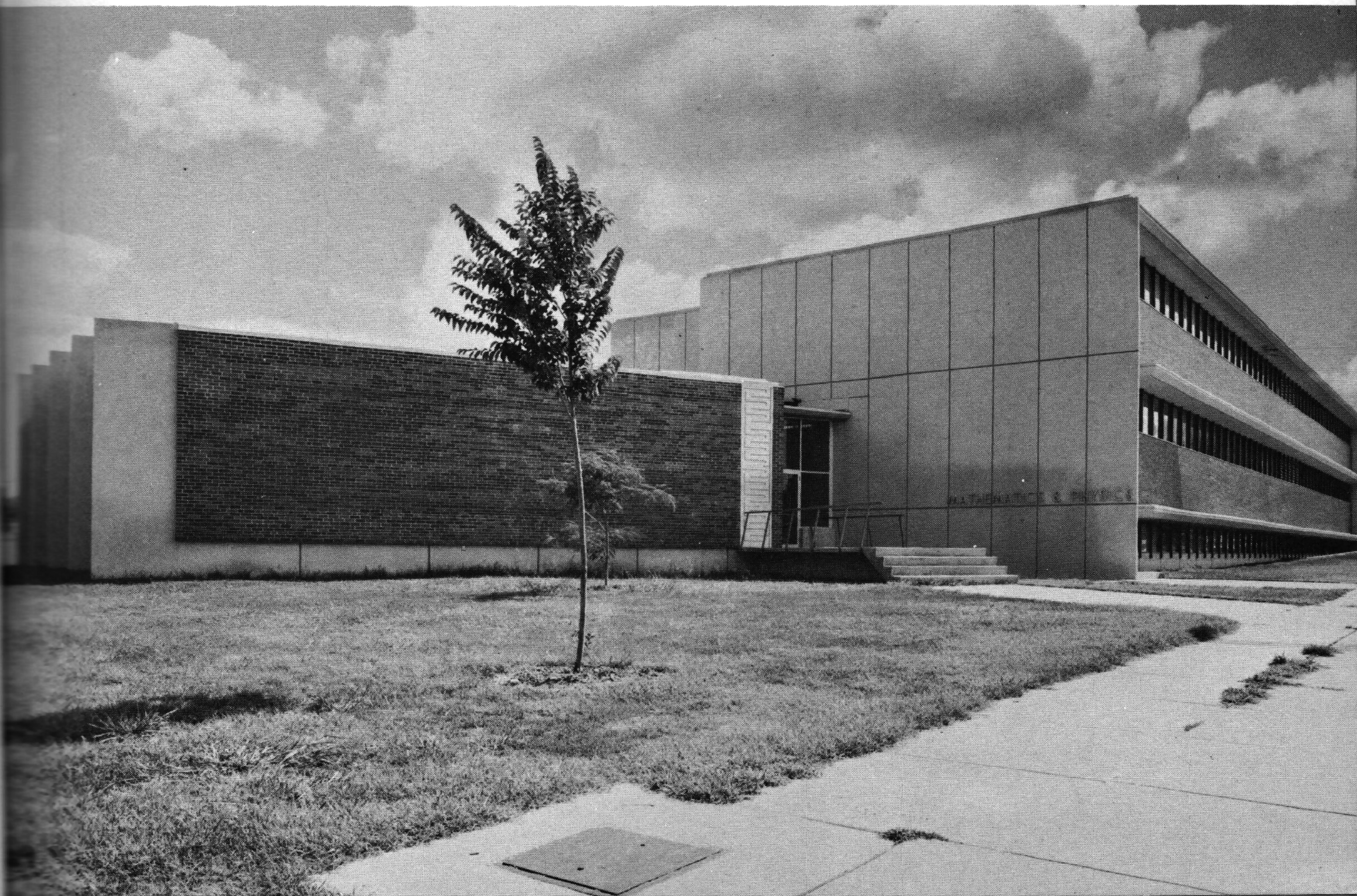


0
10
FEET
50
NORTH


Central panel for distributing electrical services viewed through the glazed window from the main corridor on the first floor.


Brick lattice screens the cooling water tower at ground level.

Main entrance and lecture hall in foreground. The three-story building is of concrete lift-slab construction.

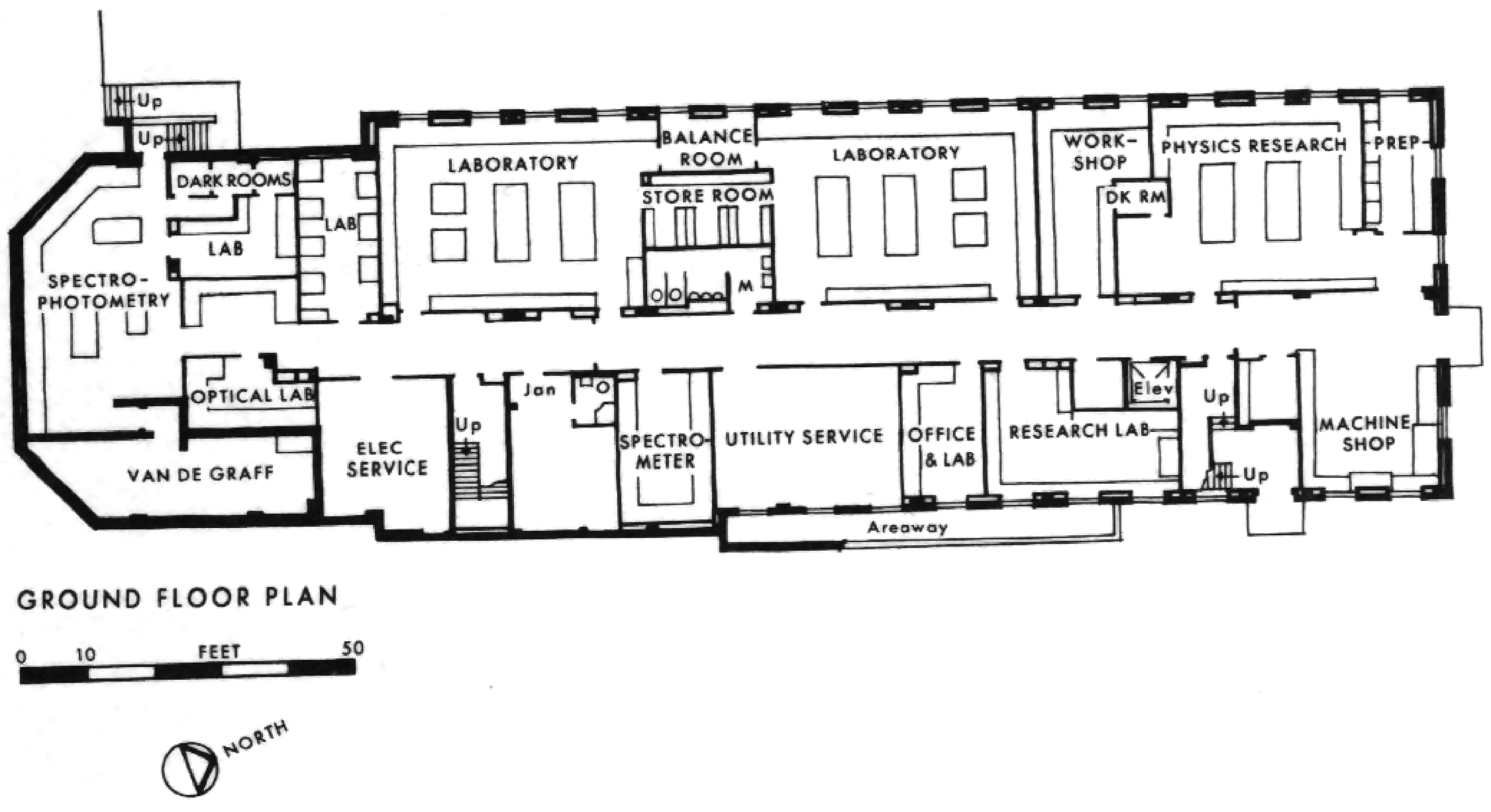


15.

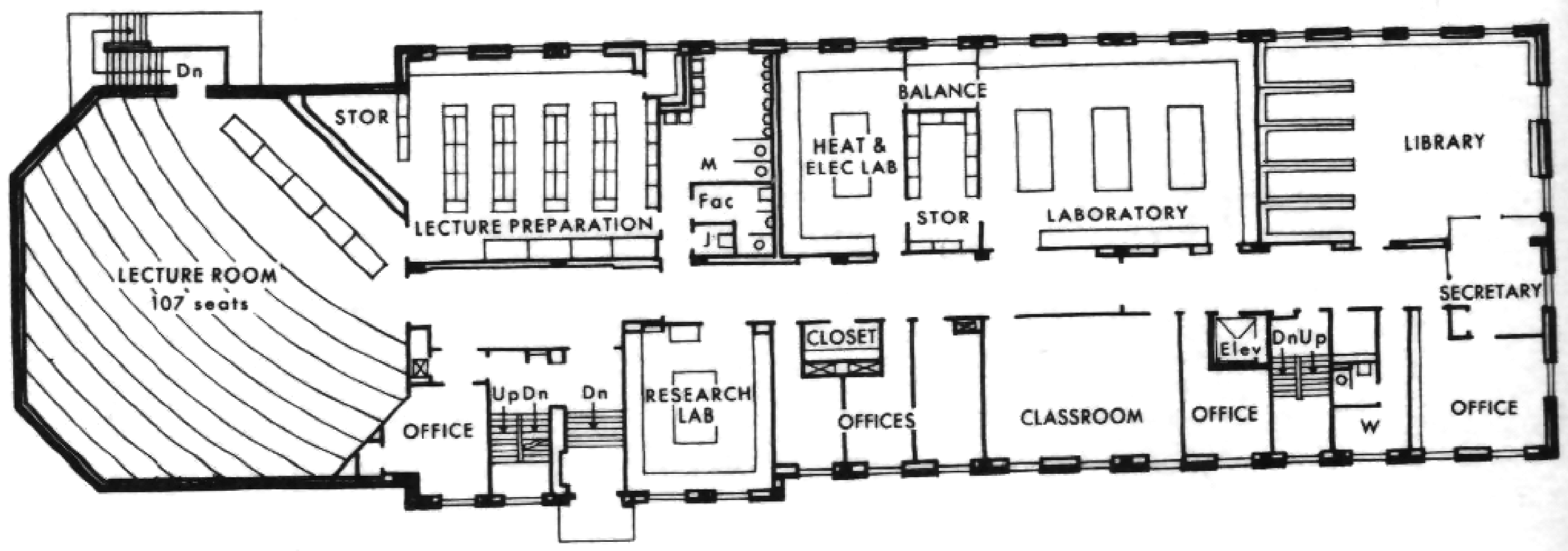
Olin Hall of Physics
Worcester Polytechnic Institute
Worcester, Massachusetts

Architects:	Rogers and Butler New York City, New York
Completed:	June 1959
Gross Area of Building:	53,066 sq. ft.
Total Cost of Building:	$972,099*
Air Conditioning:	None except nuclear emulsion research laboratory

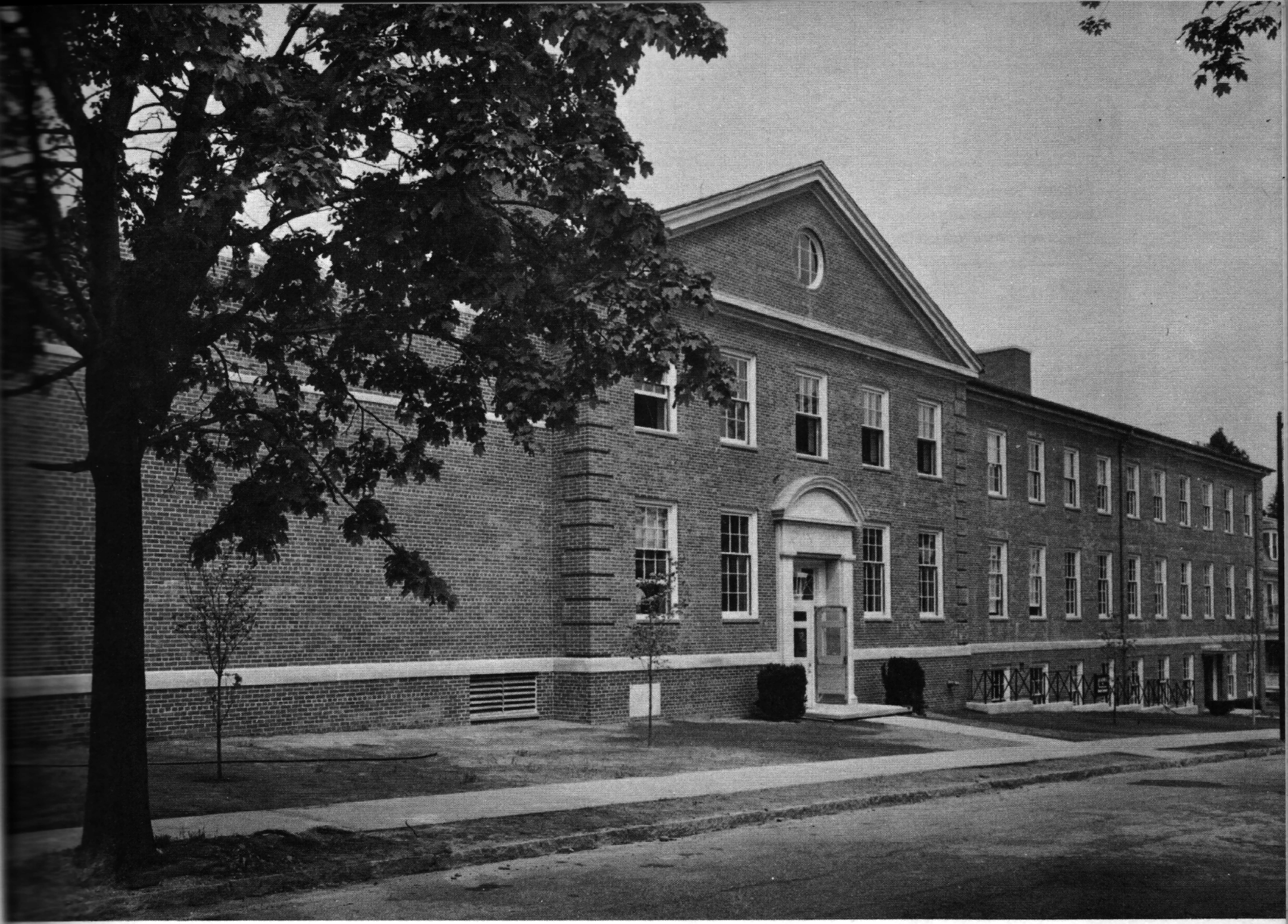
* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture. Architect's fee is not included.


Up
Up
DARK ROOMS
LAB
LAB
SPECTRO-PHOTOMETRY
LABORATORY
BALANCE ROOM
STORE ROOM
M
LABORATORY
WORK-SHOP
DK RM
PHYSICS RESEARCH
PREP
OPTICAL LAB
VAN DE GRAFF
ELEC SERVICE
Up
Jan
SPECTRO-METER
UTILITY SERVICE
OFFICE & LAB
RESEARCH LAB
Elev
Up
Up
MACHINE SHOP
Areaway
0
10
FEET
50
NORTH

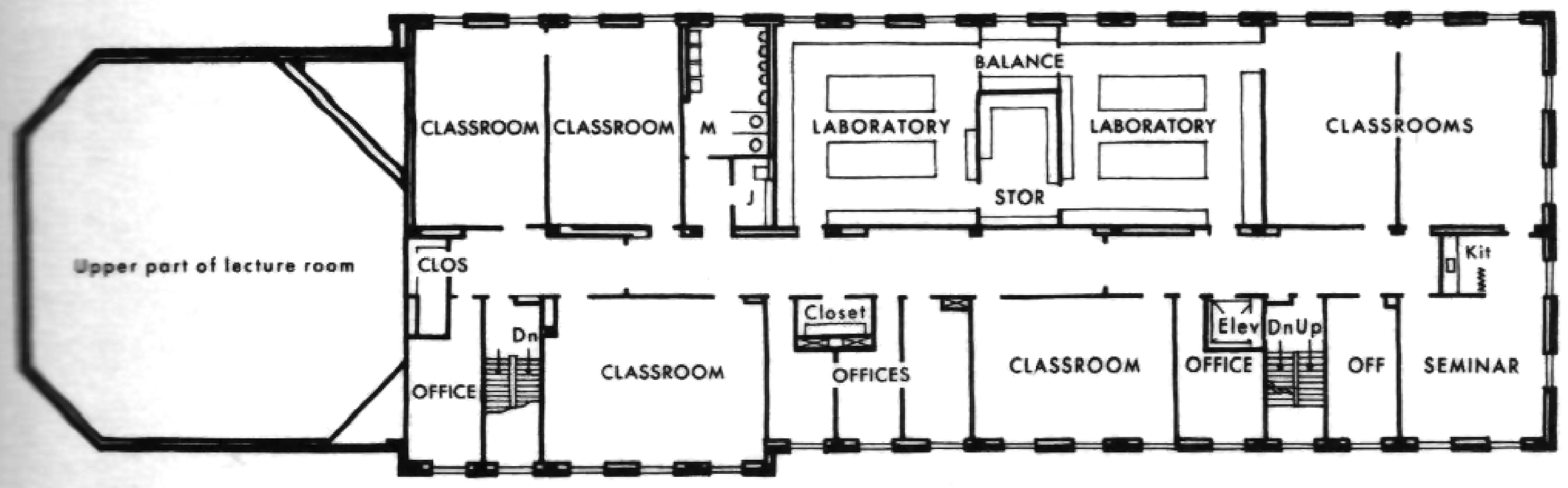
GROUND FLOOR PLAN


Dn
STOR
LECTURE PREPARATION
M
Fac
J
HEAT & ELEC LAB
BALANCE
STOR
LABORATORY
LIBRARY
LECTURE ROOM 107 seats
OFFICE
UpDn
Dn
RESEARCH LAB
CLOSET
OFFICES
CLASSROOM
Elev
DnUp
OFFICE
W
SECRETARY
OFFICE

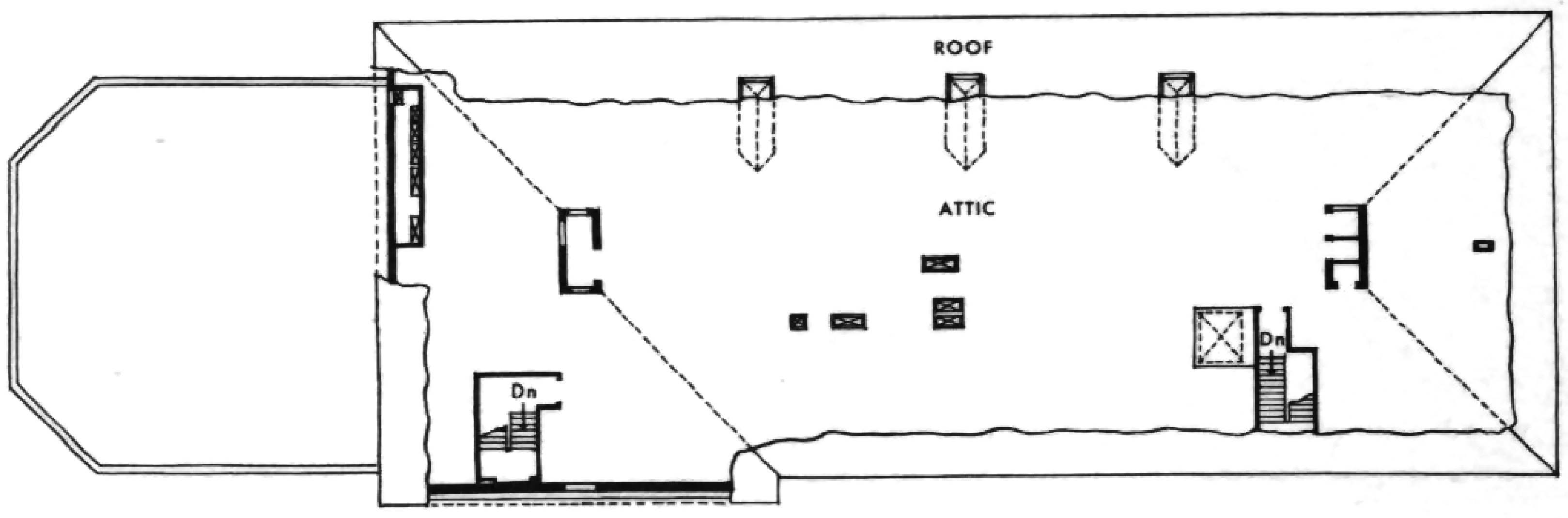
FIRST FLOOR PLAN



Street facade of building. Study of floor plans will reveal an efficient space distribution behind this formal facade. Also see Chapter 11, Figure 2 for interior view of handsome library.


Upper part of lecture room
CLASSROOM
CLASSROOM
M
J
BALANCE
LABORATORY
LABORATORY
STOR
CLASSROOMS
CLOS
Kit
Dn
OFFICE
CLASSROOM
Closet
OFFICES
CLASSROOM
Elev
Dn
Up
OFFICE
OFF
SEMINAR

SECOND FLOOR PLAN


ROOF
ATTIC
Dn
Dn

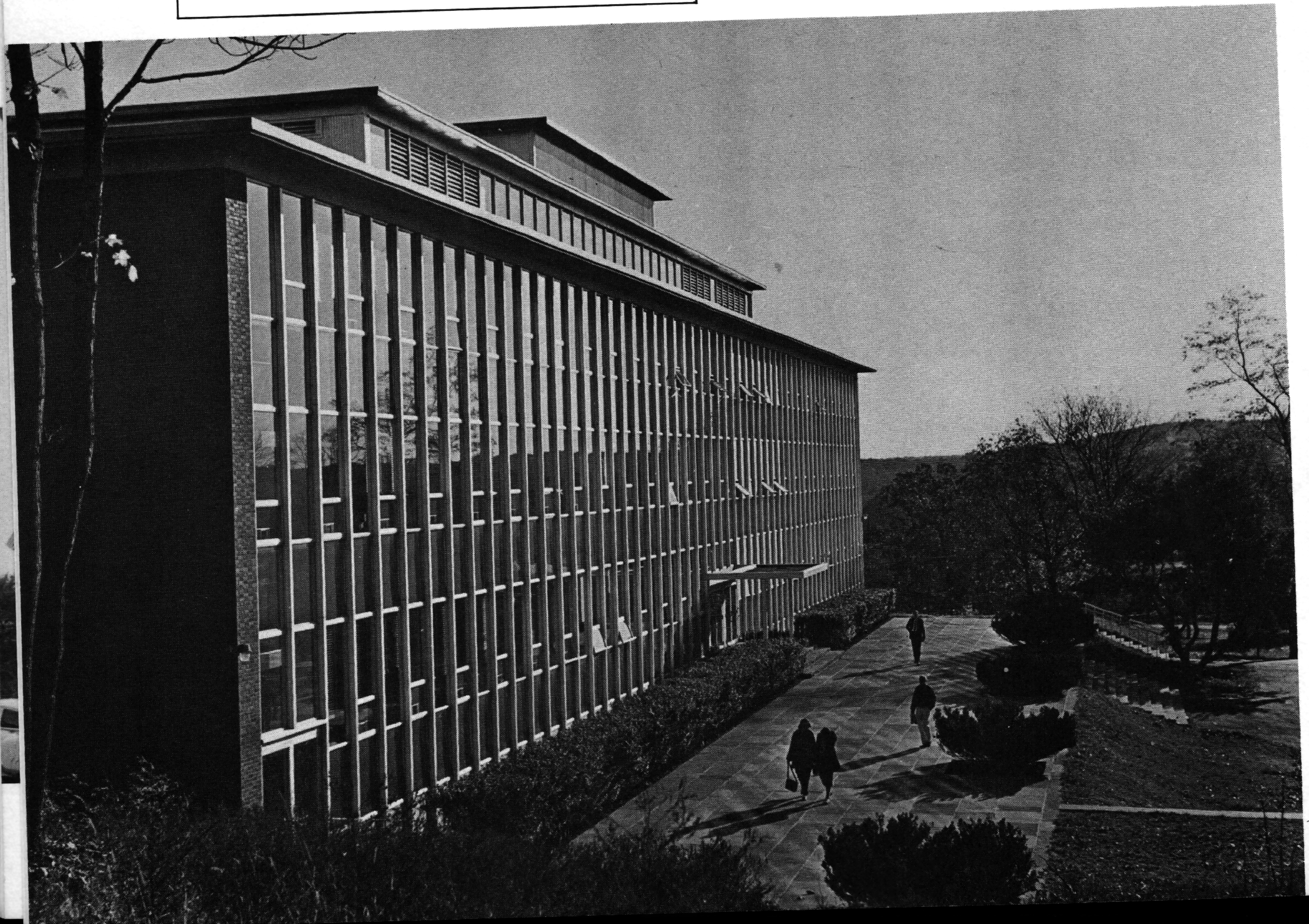
ATTIC / ROOF PLAN

16.

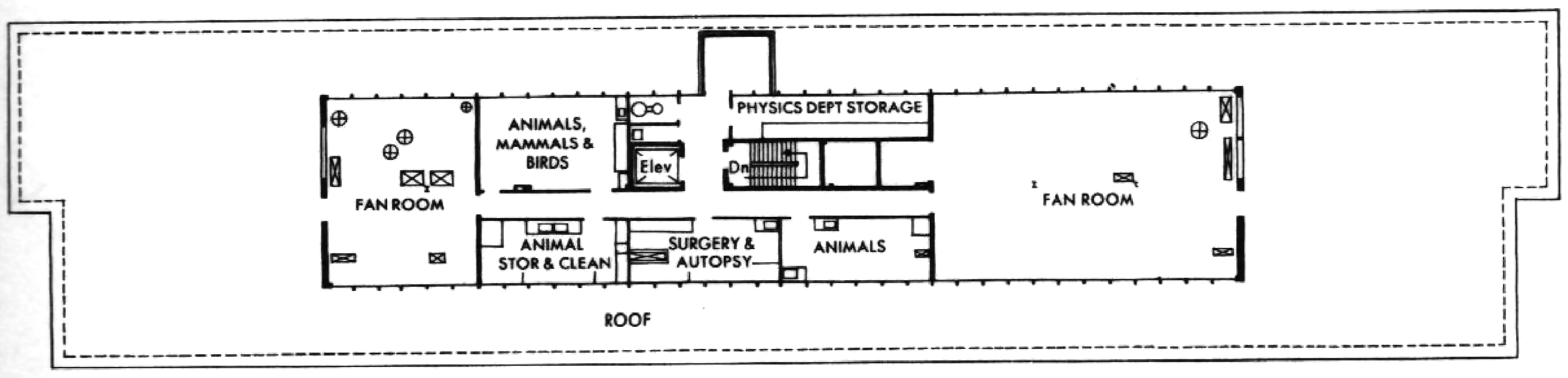
Kalman Science Building
Brandeis University
Waltham, Massachusetts

Architects:	Shepley, Bulfinch, Richardson, and Abbott Boston, Massachusetts
Completed:	Fall 1956
Gross Area of Building:	62,500 sq. ft.
Total Cost of Building:	$1,546,000*
Air Conditioning:	Individual units except for offices west side 2nd, 3rd floors which have systems. Individual units for certain equipment rooms, e.g. spectrophotometry.

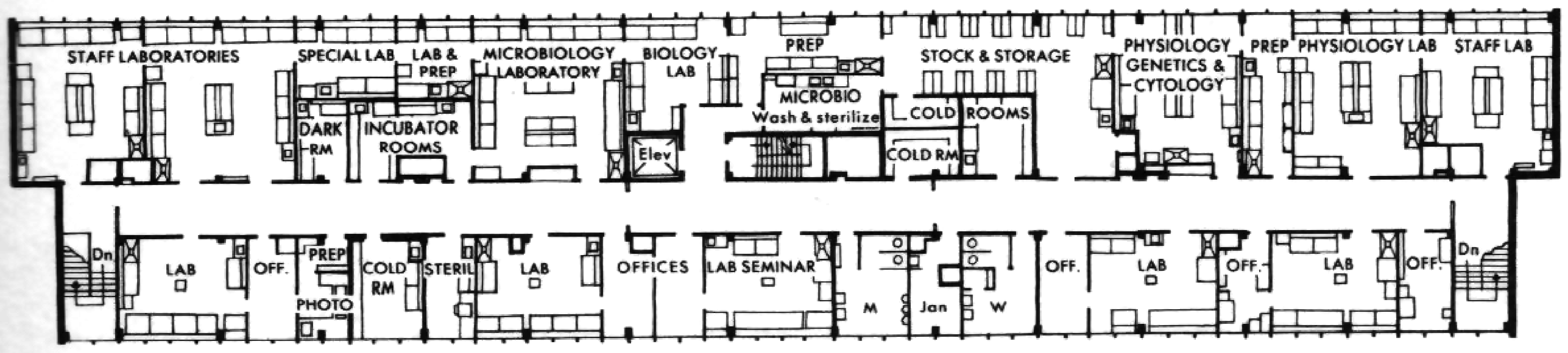
* Includes heating, ventilating, partial air conditioning, electrical and mechanical services, and laboratory furniture.



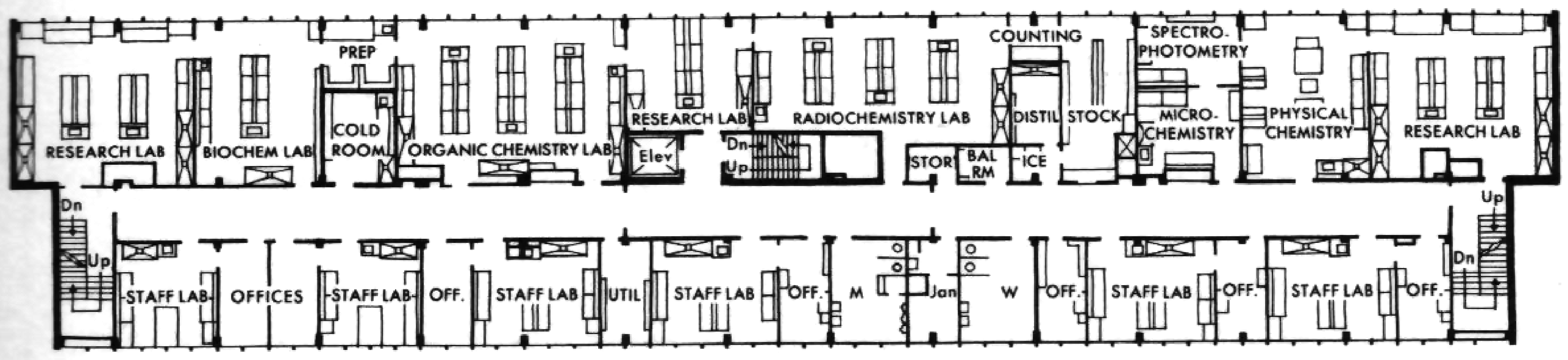
Facade of building is glazed curtain wall.


ANIMALS, MAMMALS & BIRDS
PHYSICS DEPT STORAGE
FAN ROOM
Elev
Dn
FAN ROOM
ANIMAL STOR & CLEAN
SURGERY & AUTOPSY
ANIMALS
ROOF

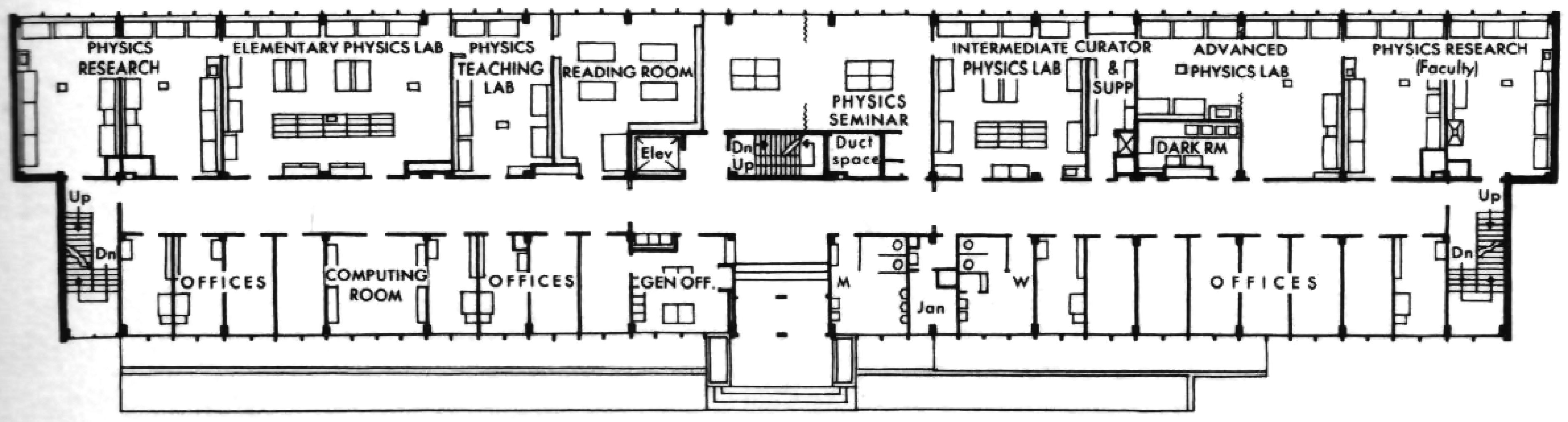
ROOF PLAN


STAFF LABORATORIES
SPECIAL LAB
LAB & PREP
MICROBIOLOGY LABORATORY
BIOLOGY LAB
PREP
MICROBIO
Wash & sterilize
STOCK & STORAGE
PHYSIOLOGY GENETICS & CYTOLOGY
PREP
PHYSIOLOGY LAB
STAFF LAB
DARK RM
INCUBATOR ROOMS
Elev
COLD ROOMS
COLD RM
Dn
LAB
OFF.
PREP
PHOTO
COLD RM
STERIL
LAB
OFFICES
LAB SEMINAR
M
Jan
W
OFF.
LAB
OFF.
LAB
OFF.
Dn

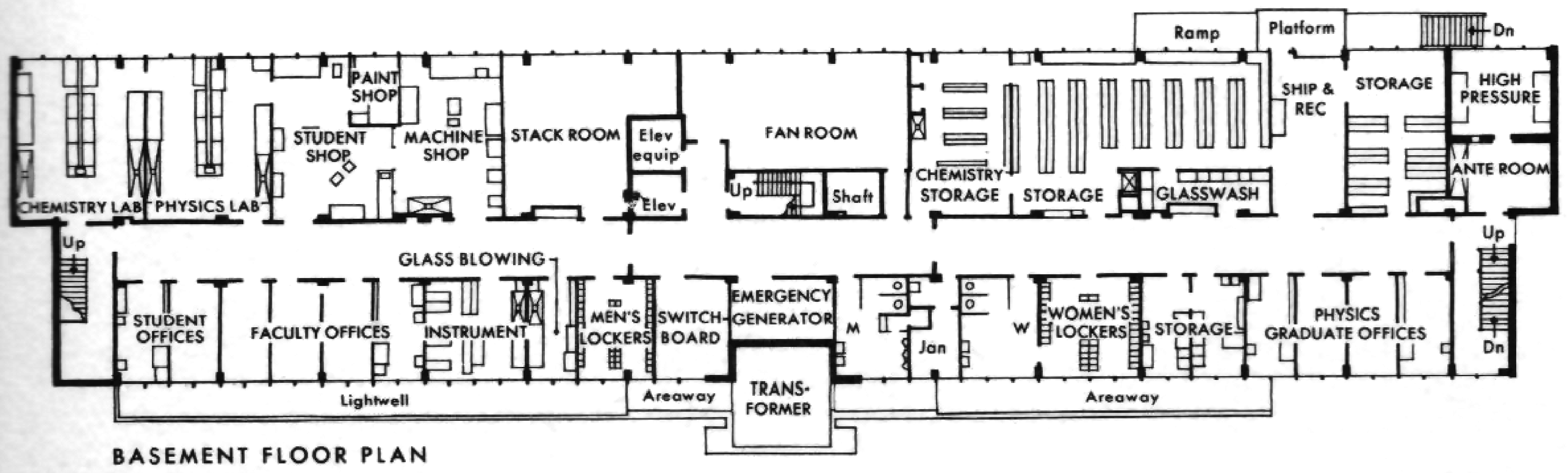
THIRD FLOOR PLAN


PREP
COUNTING
SPECTRO-PHOTOMETRY
RESEARCH LAB
BIOCHEM LAB
COLD ROOM
ORGANIC CHEMISTRY LAB
RESEARCH LAB
Elev
Dn
Up
RADIOCHEMISTRY LAB
DISTIL
STOCK
STOR
BAL RM
ICE
MICRO-CHEMISTRY
PHYSICAL CHEMISTRY
RESEARCH LAB
Dn
Up
STAFF LAB
OFFICES
STAFF LAB
OFF.
STAFF LAB
UTIL
STAFF LAB
OFF.
M
Jan
W
OFF.
STAFF LAB
OFF.
STAFF LAB
OFF.
Up
Dn

SECOND FLOOR PLAN


PHYSICS RESEARCH
ELEMENTARY PHYSICS LAB
PHYSICS TEACHING LAB
READING ROOM
Elev
Dn
Up
PHYSICS SEMINAR
Duct space
INTERMEDIATE PHYSICS LAB
CURATOR & SUPP
ADVANCED PHYSICS LAB
DARK RM
PHYSICS RESEARCH (Faculty)
Up
Dn
OFFICES
COMPUTING ROOM
OFFICES
GEN OFF.
M
Jan
W
OFFICES
Up
Dn

FIRST FLOOR PLAN


Ramp
Platform
Dn
PAINT SHOP
STUDENT SHOP
MACHINE SHOP
STACK ROOM
Elev equip
FAN ROOM
Up
Shaft
Elev
CHEMISTRY STORAGE
STORAGE
GLASSWASH
SHIP & REC
STORAGE
HIGH PRESSURE
ANTE ROOM
CHEMISTRY LAB
PHYSICS LAB
Up
GLASS BLOWING
STUDENT OFFICES
FACULTY OFFICES
INSTRUMENT
MEN'S LOCKERS
SWITCH-BOARD
EMERGENCY GENERATOR
M
Jan
W
WOMEN'S LOCKERS
STORAGE
PHYSICS GRADUATE OFFICES
Up
Dn
Lightwell
Areaway
TRANS-FORMER
Areaway
0
10
FEET
50
NORTH

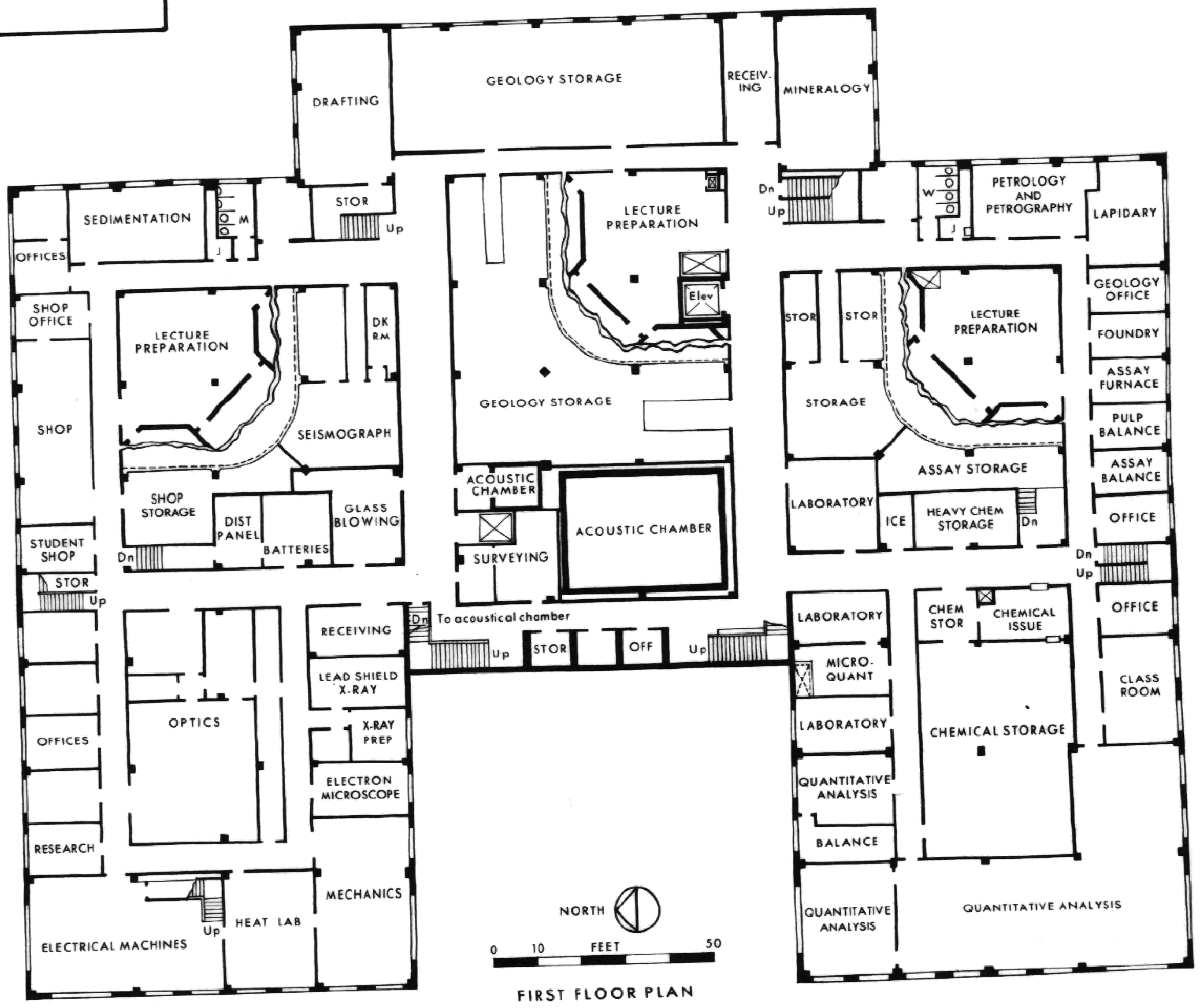
BASEMENT FLOOR PLAN

17.

Carl F. Eyring Physical Science Center
Brigham Young University
Provo, Utah

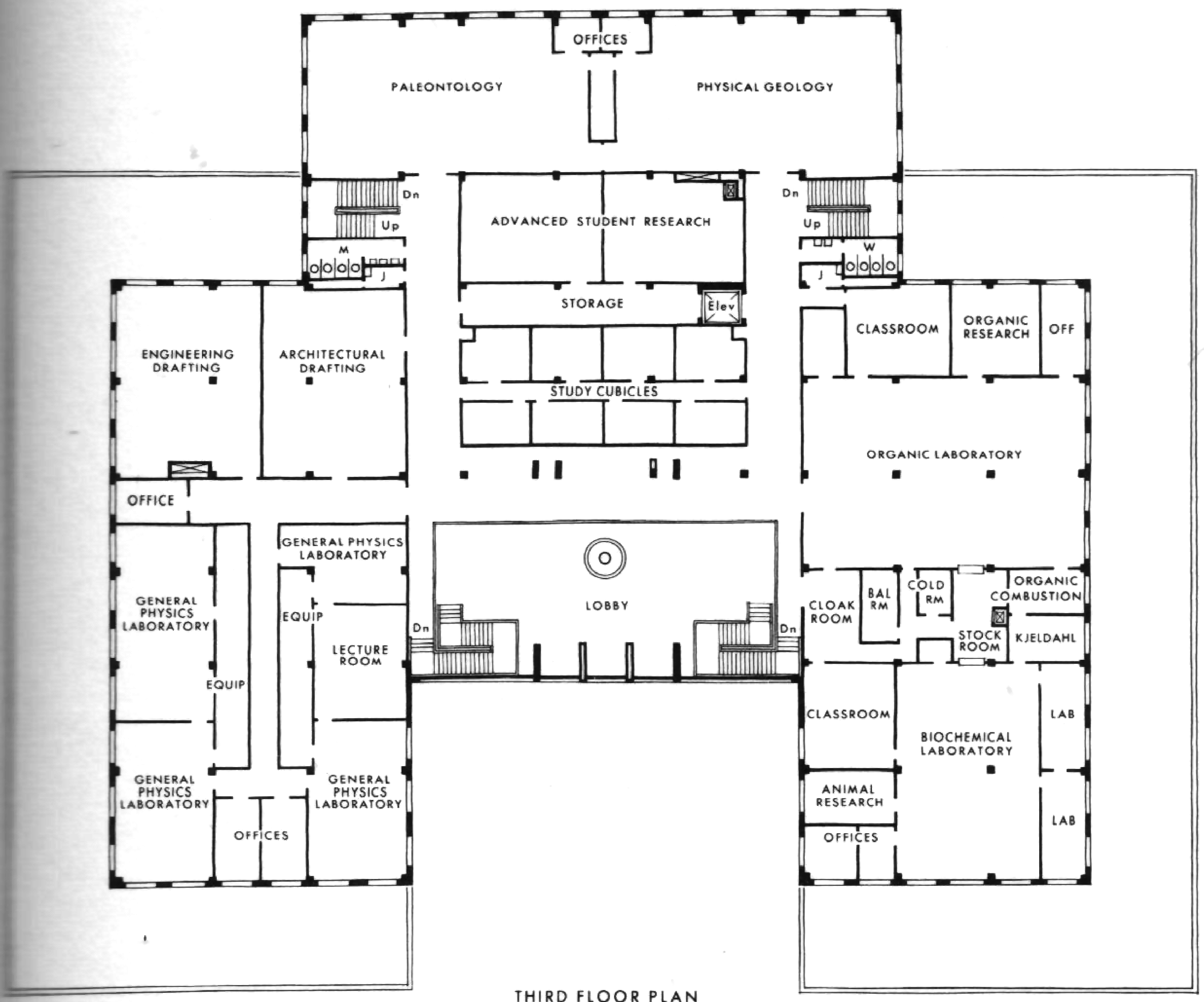
Architects:	Fred L. Markham Provo, Utah
Completed:	October 1950
Gross Area of Building:	147,467 sq. ft.
Total Cost of Building:	$2,000,000*
Air Conditioning:	None

* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

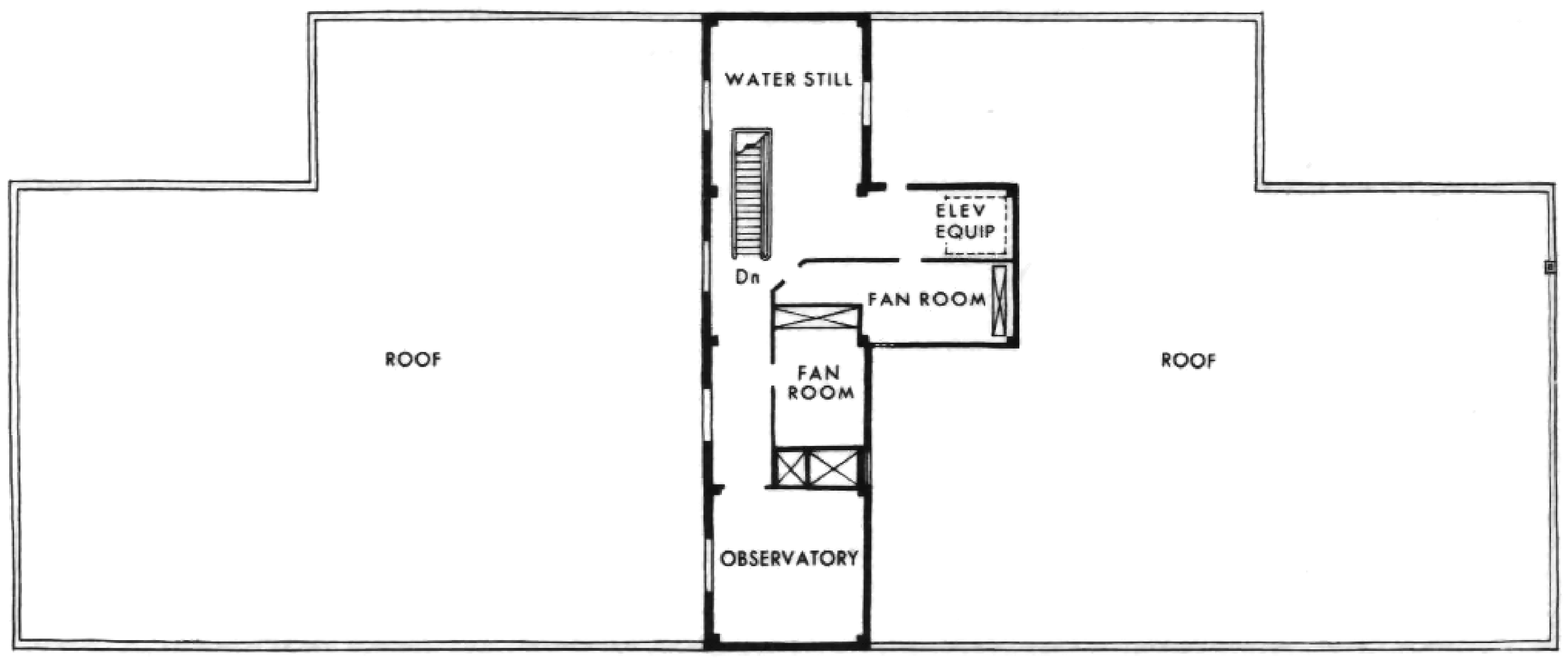

DRAFTING
GEOLOGY STORAGE
RECEIV-ING
MINERALOGY
SEDIMENTATION
STOR
Up
Dn
LECTURE PREPARATION
Elev
PETROLOGY AND PETROGRAPHY
LAPIDARY
OFFICES
SHOP OFFICE
LECTURE PREPARATION
DK RM
STOR
STOR
LECTURE PREPARATION
GEOLOGY OFFICE
FOUNDRY
ASSAY FURNACE
SHOP
SEISMOGRAPH
GEOLOGY STORAGE
STORAGE
PULP BALANCE
ASSAY BALANCE
ASSAY STORAGE
SHOP STORAGE
DIST PANEL
BATTERIES
GLASS BLOWING
ACOUSTIC CHAMBER
ACOUSTIC CHAMBER
LABORATORY
ICE
HEAVY CHEM STORAGE
OFFICE
STUDENT SHOP
SURVEYING
STOR
CHEM STOR
CHEMICAL ISSUE
OFFICE
RECEIVING
To acoustical chamber
LABORATORY
STOR
OFF
LEAD SHIELD X-RAY
MICRO. QUANT
CLASS ROOM
OFFICES
OPTICS
X-RAY PREP
LABORATORY
CHEMICAL STORAGE
ELECTRON MICROSCOPE
QUANTITATIVE ANALYSIS
RESEARCH
BALANCE
MECHANICS
NORTH
QUANTITATIVE ANALYSIS
QUANTITATIVE ANALYSIS
ELECTRICAL MACHINES
HEAT LAB
0 10 FEET 50

FIRST FLOOR PLAN

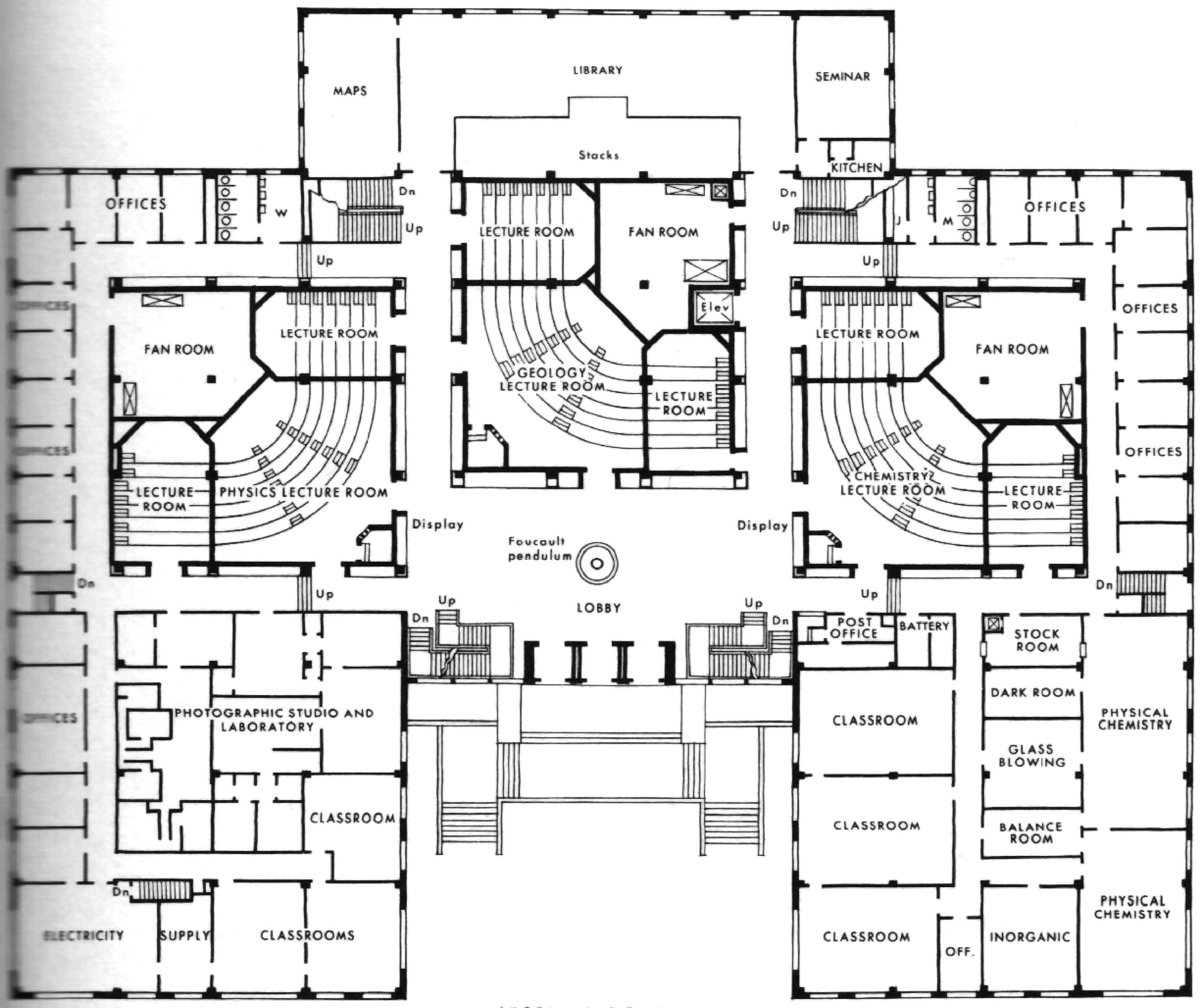
Exterior as viewed from the main campus. This is one of the largest and more imposing examples of science buildings.


OFFICES
PALEONTOLOGY
PHYSICAL GEOLOGY
Dn
Up
M
J
W
ADVANCED STUDENT RESEARCH
STORAGE
Elev
STUDY CUBICLES
ENGINEERING DRAFTING
ARCHITECTURAL DRAFTING
CLASSROOM
ORGANIC RESEARCH
OFF
ORGANIC LABORATORY
OFFICE
GENERAL PHYSICS LABORATORY
EQUIP
LECTURE ROOM
LOBBY
CLOAK ROOM
BAL RM
COLD RM
ORGANIC COMBUSTION
STOCK ROOM
KJELDAHL
BIOCHEMICAL LABORATORY
LAB
ANIMAL RESEARCH
OFFICES

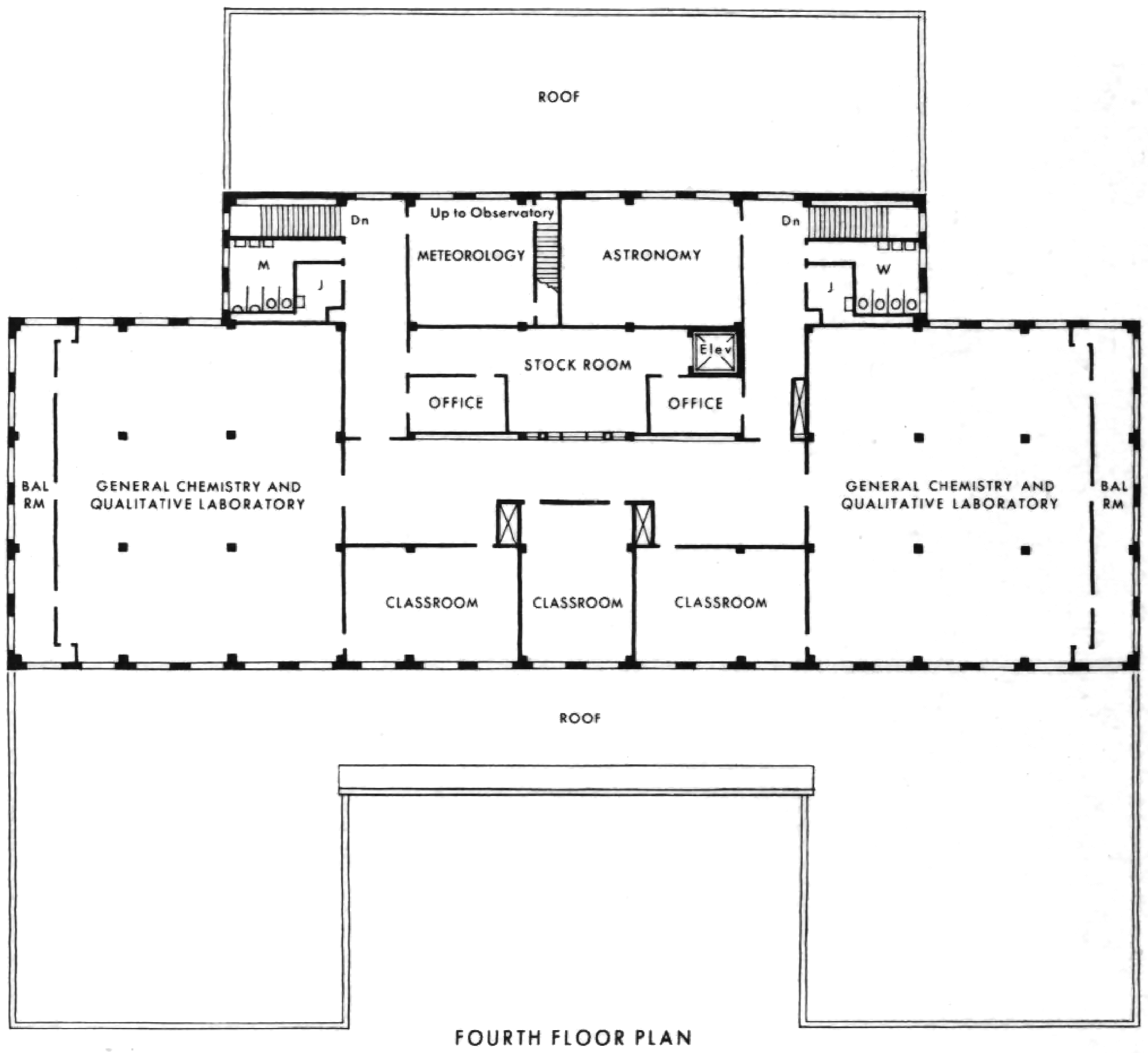
THIRD FLOOR PLAN


WATER STILL
ELEV EQUIP
Dn
FAN ROOM
ROOF
OBSERVATORY

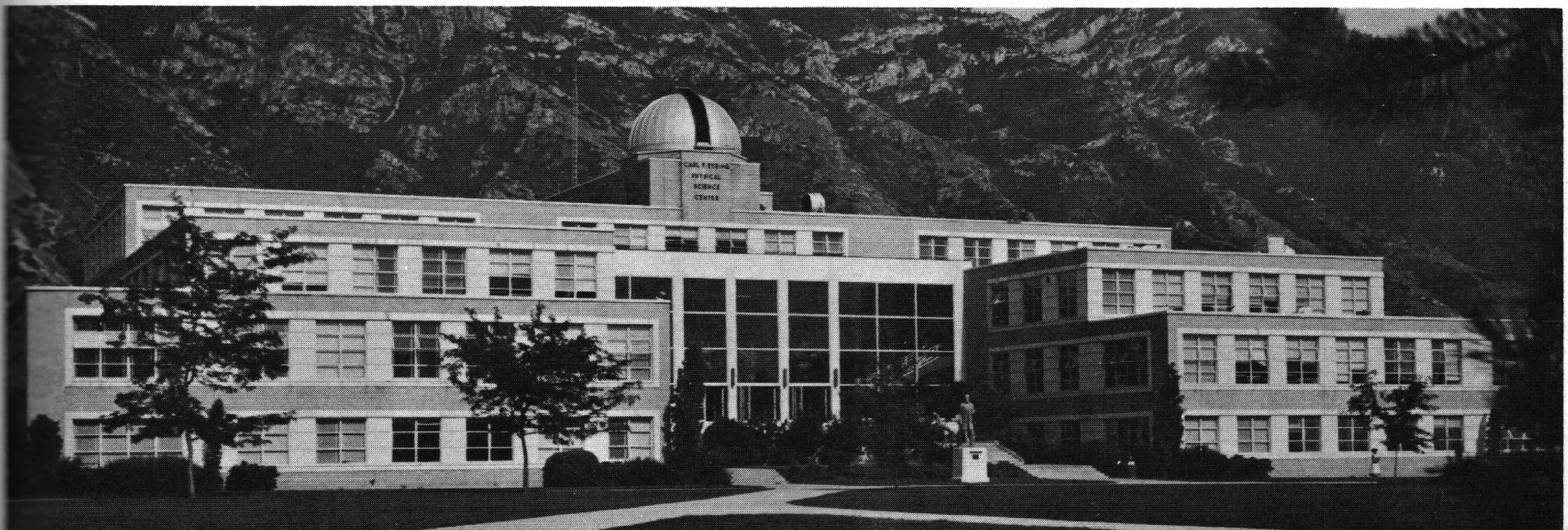
FIFTH FLOOR PLAN


MAPS
LIBRARY
SEMINAR
Stacks
KITCHEN
OFFICES
W
M
J
Dn
Up
LECTURE ROOM
FAN ROOM
Elev
GEOLOGY LECTURE ROOM
PHYSICS LECTURE ROOM
CHEMISTRY LECTURE ROOM
Display
Foucault pendulum
LOBBY
POST OFFICE
BATTERY
STOCK ROOM
DARK ROOM
GLASS BLOWING
BALANCE ROOM
PHYSICAL CHEMISTRY
PHOTOGRAPHIC STUDIO AND LABORATORY
CLASSROOM
CLASSROOMS
ELECTRICITY
SUPPLY
INORGANIC
OFF.

SECOND FLOOR PLAN


ROOF
Dn
Up to Observatory
METEOROLOGY
ASTRONOMY
M
J
W
STOCK ROOM
Elev
OFFICE
BAL RM
GENERAL CHEMISTRY AND QUALITATIVE LABORATORY
CLASSROOM

FOURTH FLOOR PLAN


CARL F. EYRING PHYSICAL SCIENCE CENTER

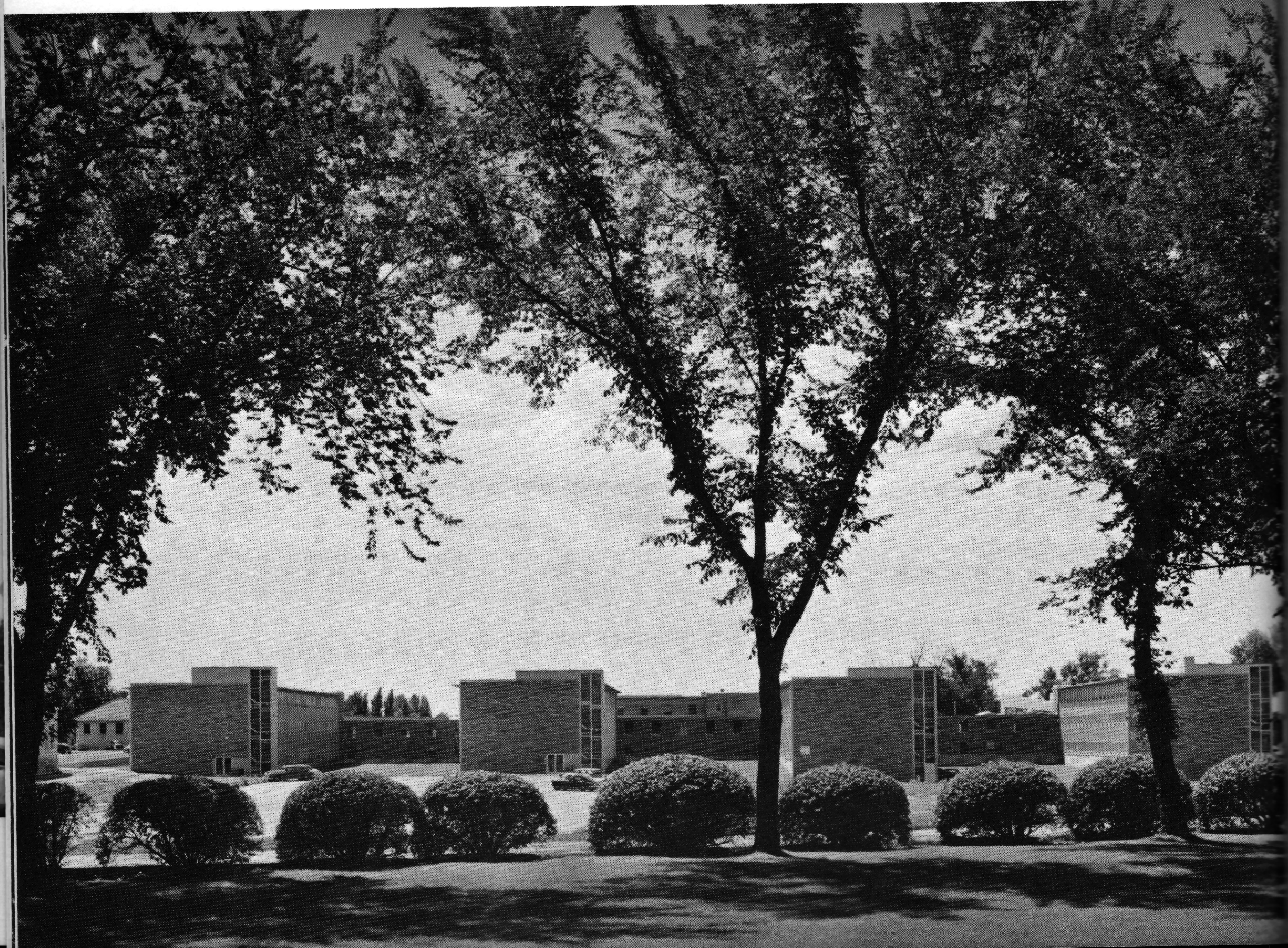
18.

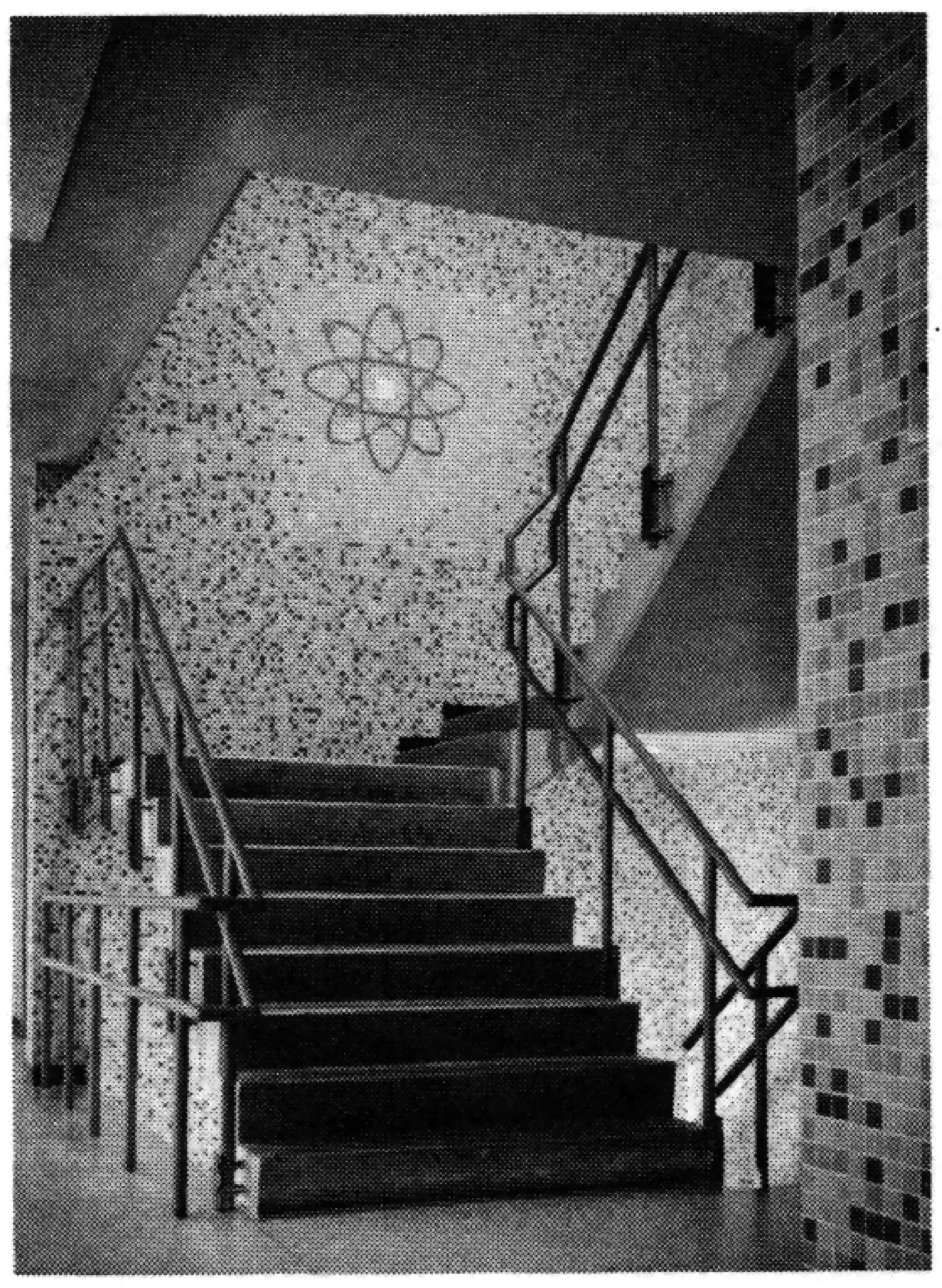
Engineering Building
Colorado State University
Fort Collins, Colorado

Architects:	James M. Hunter, and Associates Boulder, Colorado
Completed:	1958
Gross Area of Building:	116,532 sq. ft.
Total Cost of Building:	$1,700,000*
Air Conditioning:	None

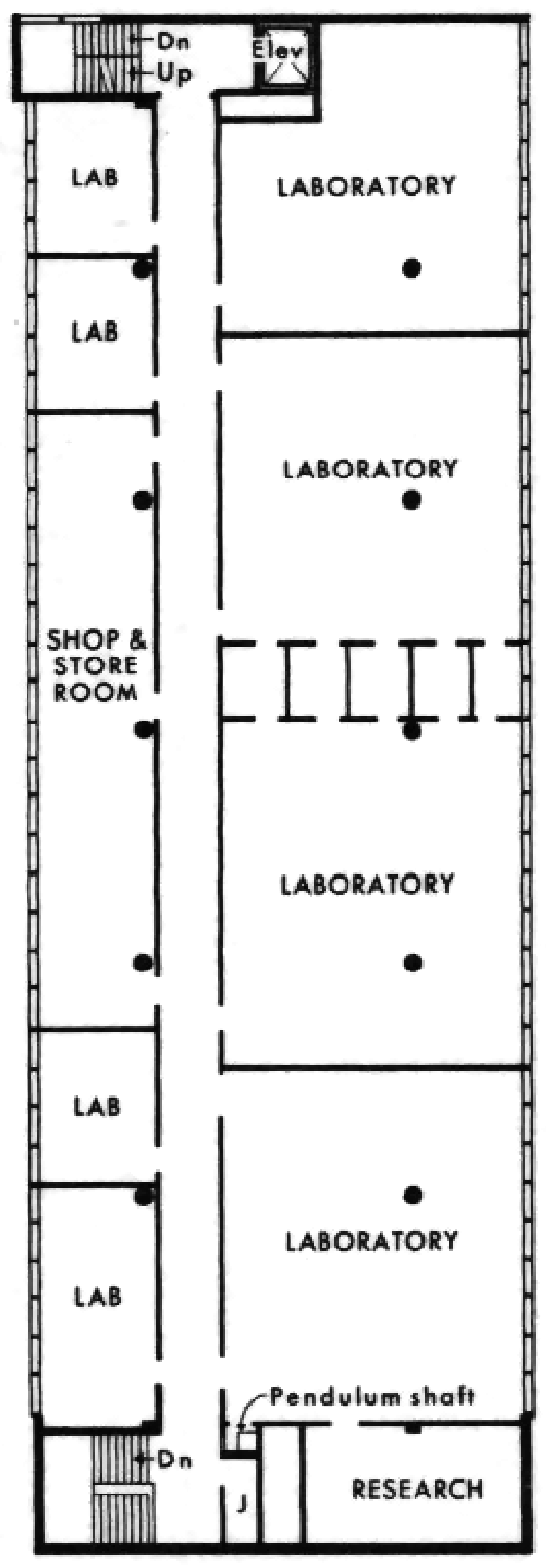
* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

Three-story wings of the Engineering Building extend off two-story office "spine." Lecture room is behind first wing on right. Wings are unique in two-column cantilever system described in Chapter 3.

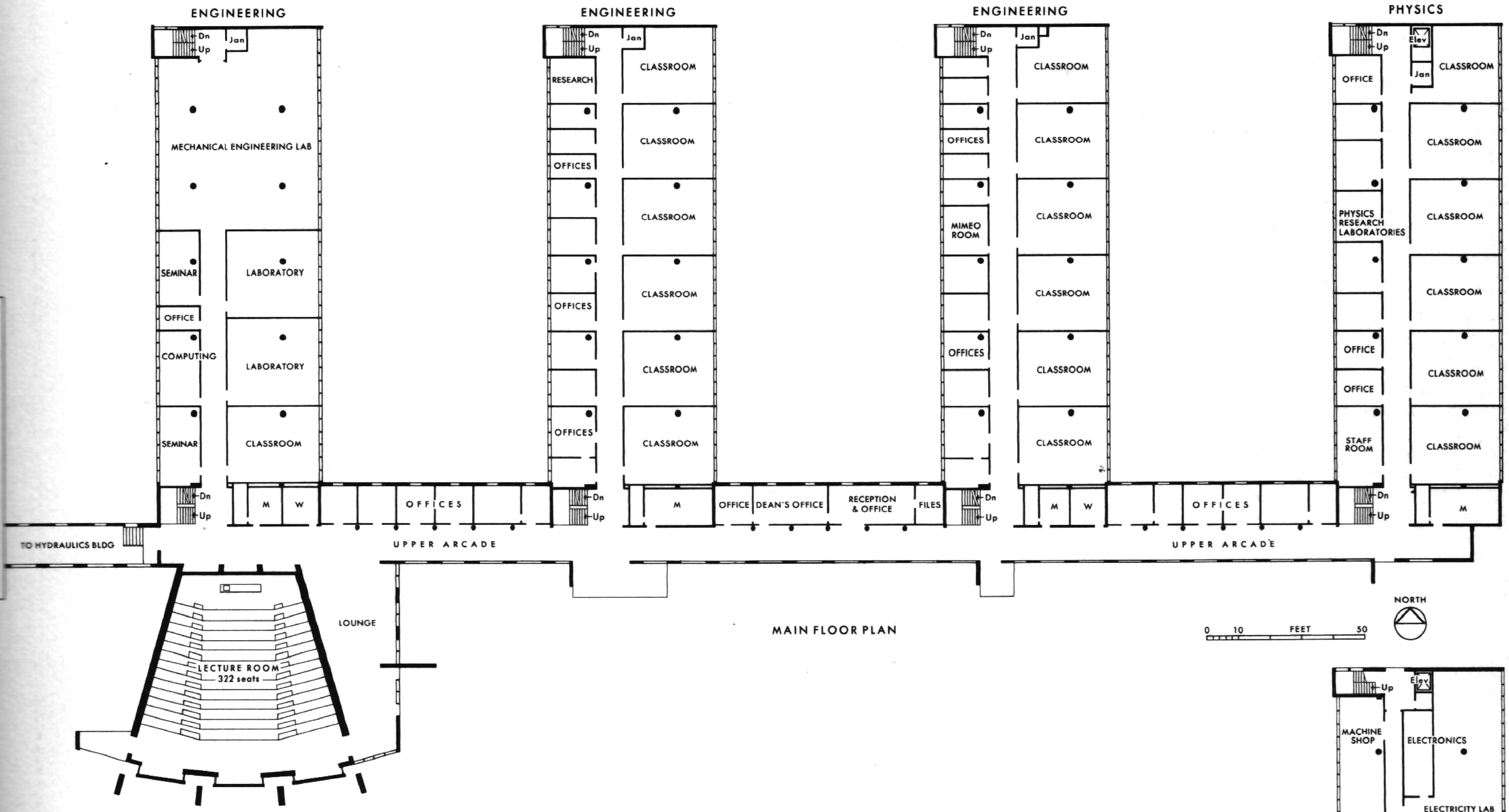




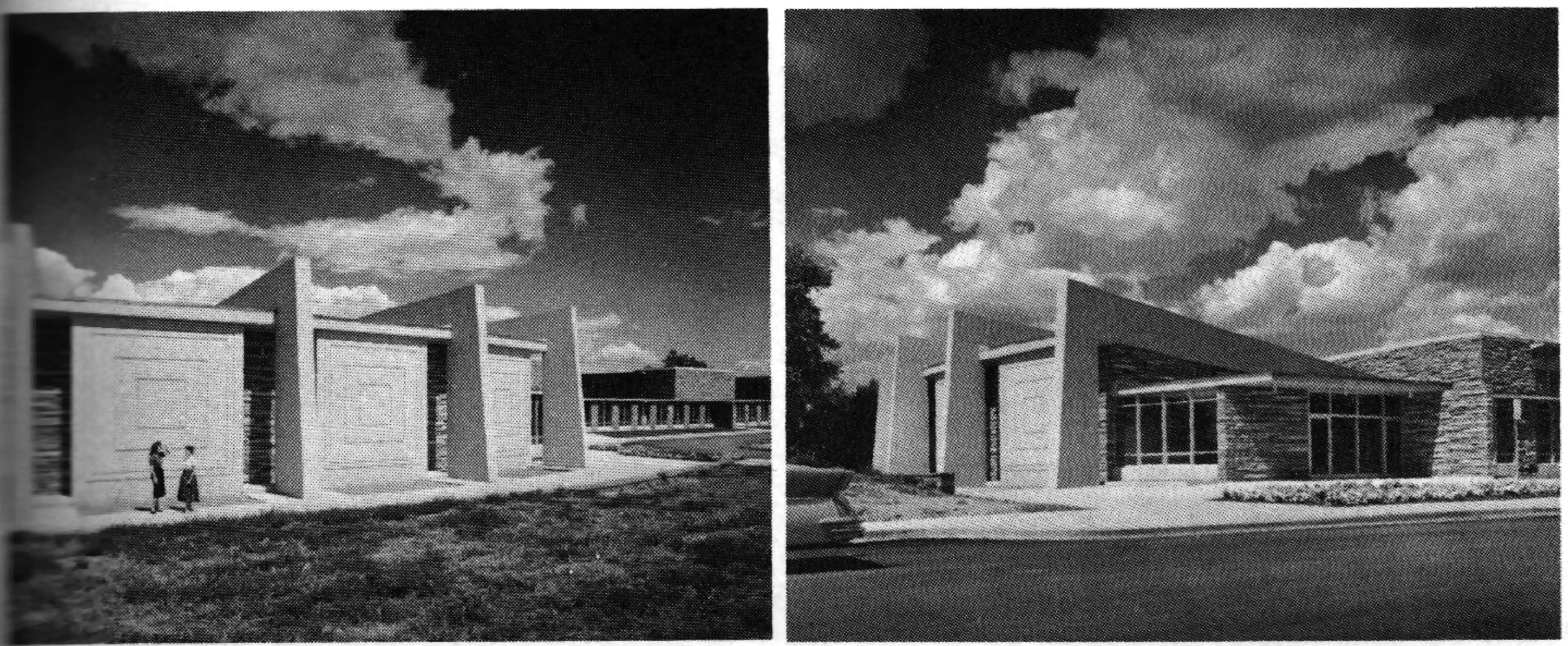
Tile in stair hall is both lively and durable.


Dn
Up
Elev
LAB
LABORATORY
LAB
LABORATORY
SHOP & STORE ROOM
LABORATORY
LAB
LABORATORY
LAB
Pendulum shaft
Dn
J
RESEARCH

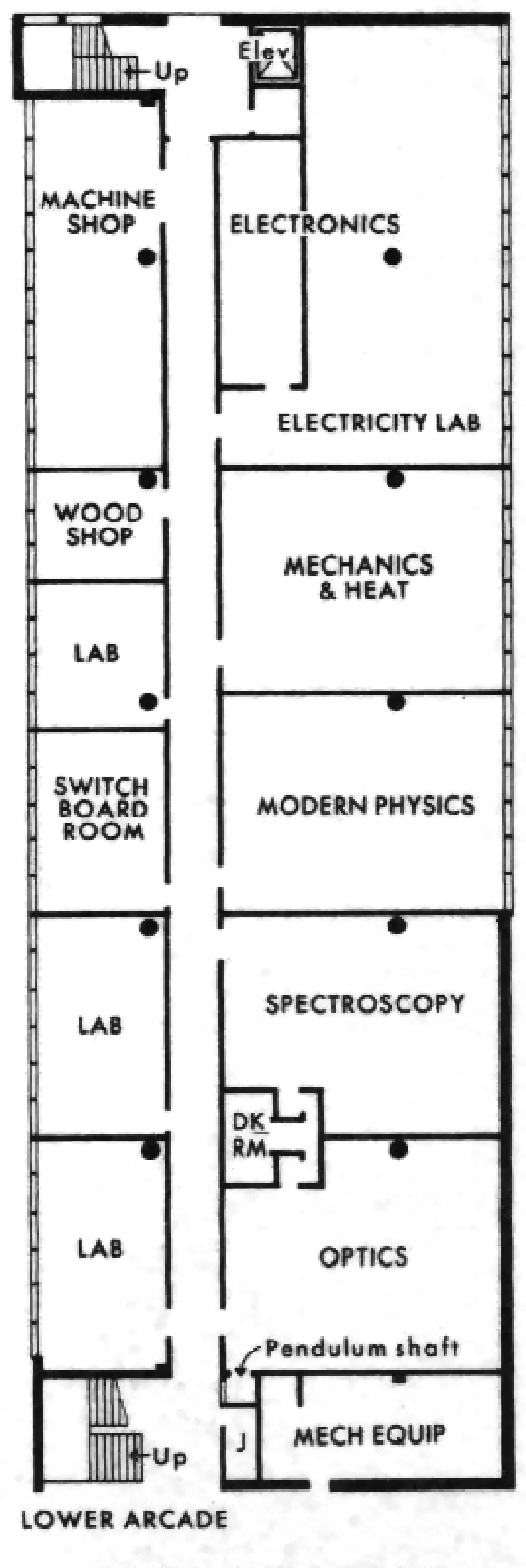
UPPER FLOOR PLAN


ENGINEERING
Dn
Up
Jan
MECHANICAL ENGINEERING LAB
SEMINAR
LABORATORY
OFFICE
COMPUTING
LABORATORY
SEMINAR
CLASSROOM
M
W
OFFICES
TO HYDRAULICS BLDG
UPPER ARCADE
LECTURE ROOM
322 seats
LOUNGE
ENGINEERING
Jan
RESEARCH
CLASSROOM
OFFICES
CLASSROOM
CLASSROOM
OFFICES
CLASSROOM
CLASSROOM
OFFICES
CLASSROOM
M
OFFICE
DEAN'S OFFICE
RECEPTION & OFFICE
FILES
ENGINEERING
Jan
CLASSROOM
OFFICES
CLASSROOM
CLASSROOM
MIMEO ROOM
CLASSROOM
OFFICES
CLASSROOM
CLASSROOM
M
W
OFFICES
UPPER ARCADE
PHYSICS
Elev
Jan
OFFICE
CLASSROOM
CLASSROOM
PHYSICS RESEARCH LABORATORIES
CLASSROOM
CLASSROOM
OFFICE
OFFICE
CLASSROOM
STAFF ROOM
CLASSROOM
M
NORTH
0
10
FEET
50

MAIN FLOOR PLAN



Two exterior views of lecture room. Large rigid frames support the roof.


Up
Elev
MACHINE SHOP
ELECTRONICS
ELECTRICITY LAB
WOOD SHOP
MECHANICS & HEAT
LAB
SWITCH BOARD ROOM
MODERN PHYSICS
SPECTROSCOPY
LAB
DK RM
LAB
OPTICS
Pendulum shaft
Up
J
MECH EQUIP
LOWER ARCADE

LOWER FLOOR PLAN

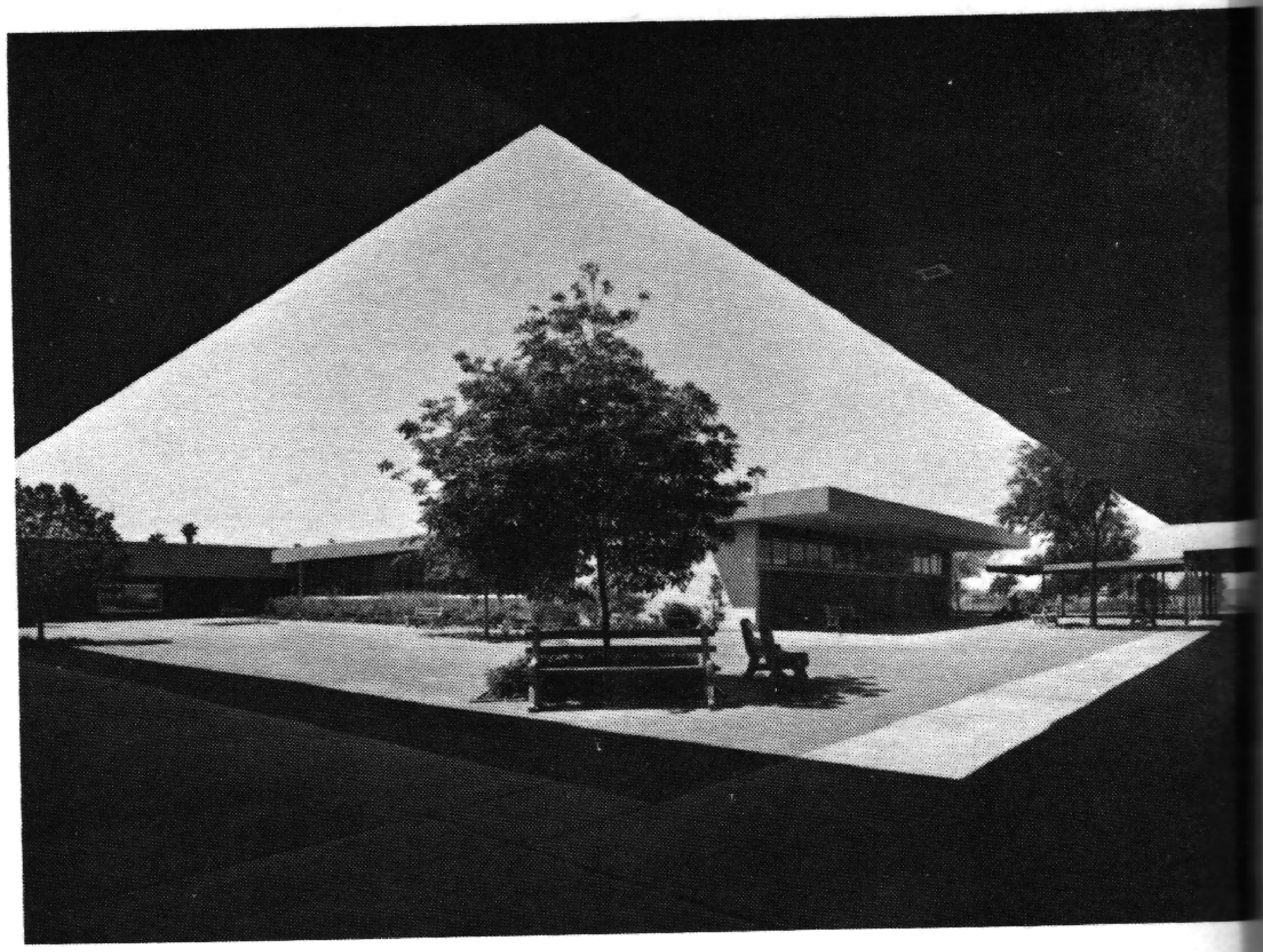
19.

Physics Building
El Camino College
El Camino, California

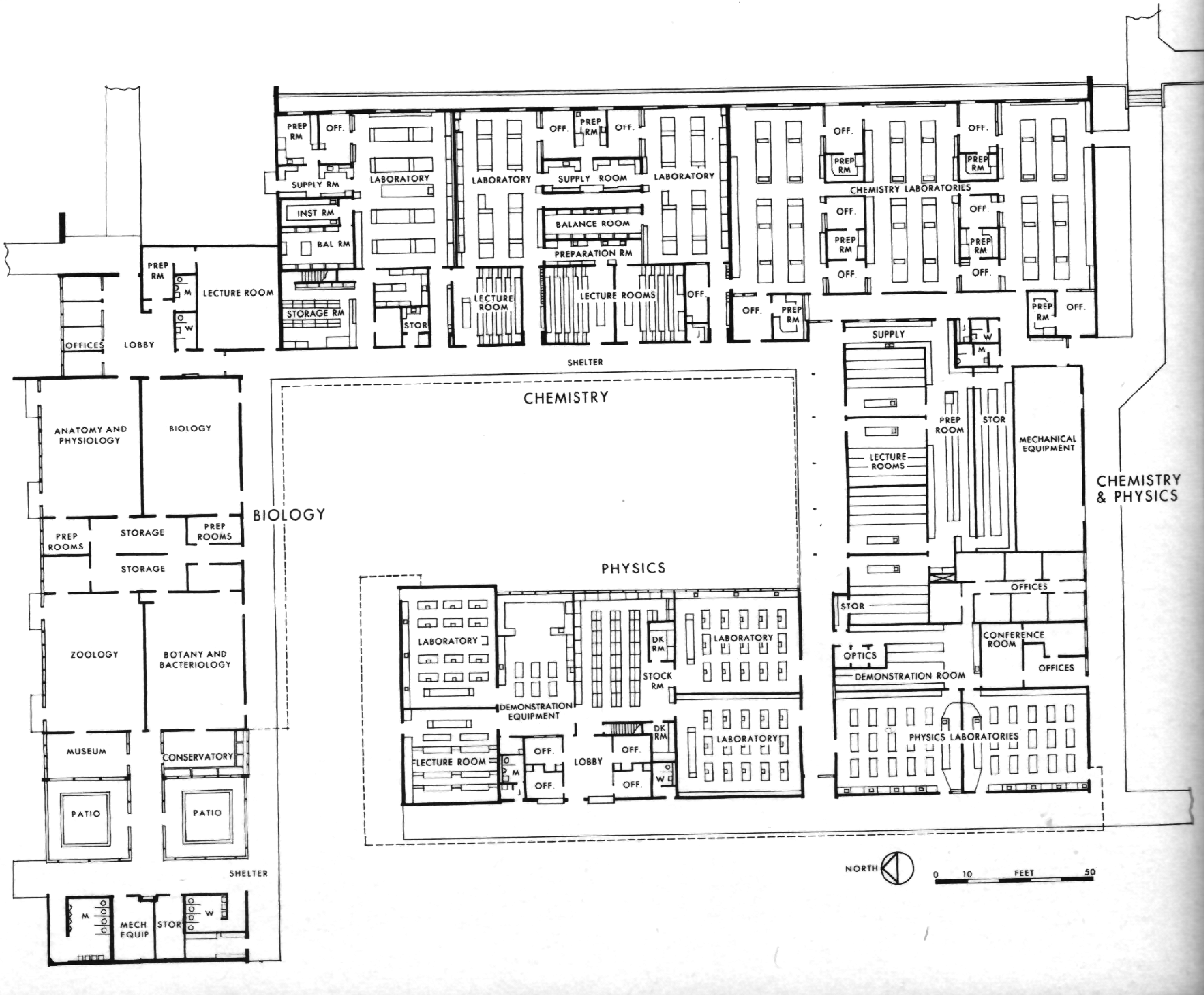
Architects:	Smith, Powell and Morgridge Los Angeles, California
Completed:	1st unit—Spring 1957 2nd unit—September 1959
Gross Area of Building:	1st unit—12,139 sq. ft. 2nd unit —5,130 sq. ft. (approximate)*
Total Cost of Building:	1st unit —$362,281 2nd unit—$150,000 (approximate)**
Air Conditioning:	None

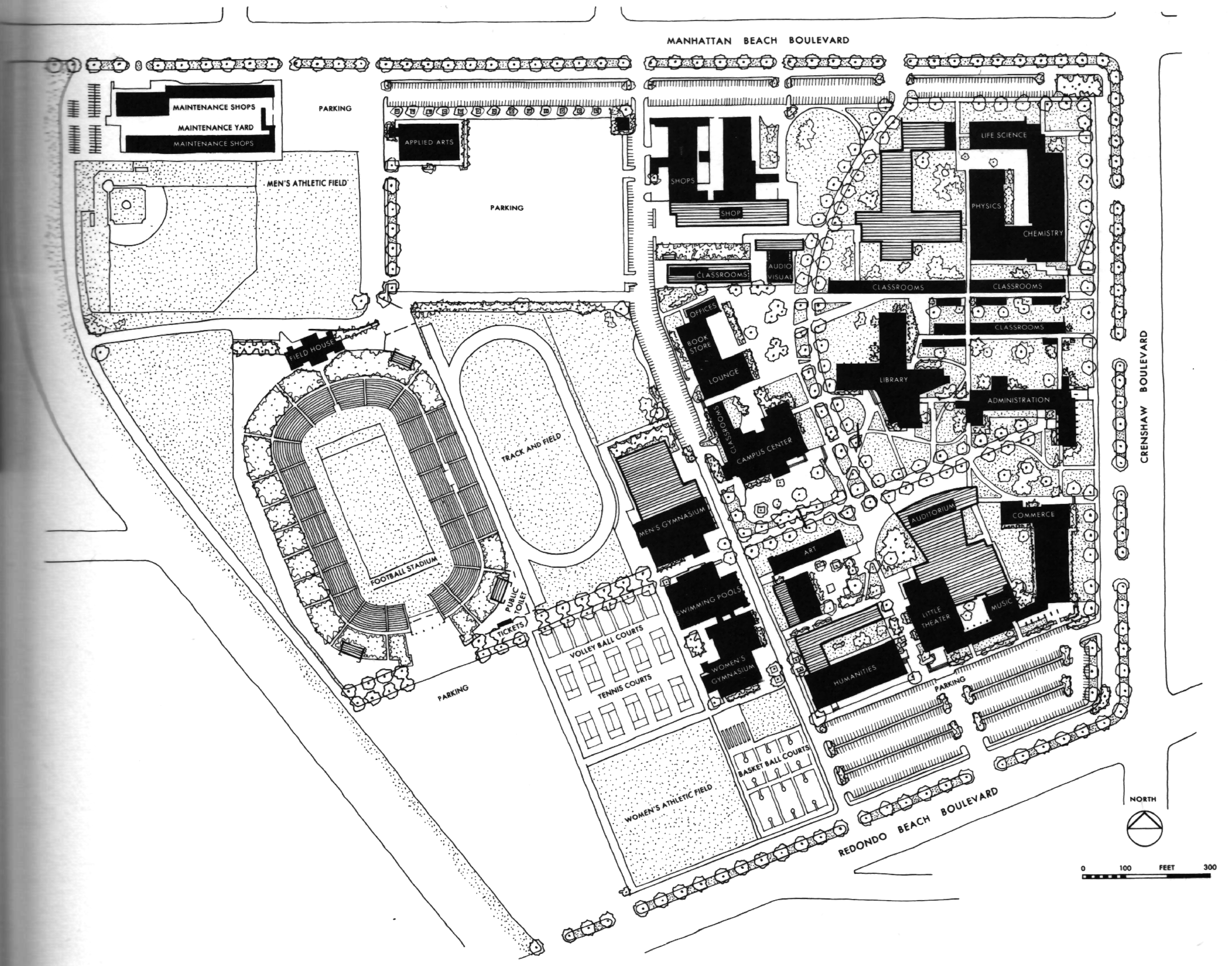
* Approximate because 2nd units of physics building and chemistry building are in a wing which join the first units of each building together and all figures include both portions of the second unit.

** Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

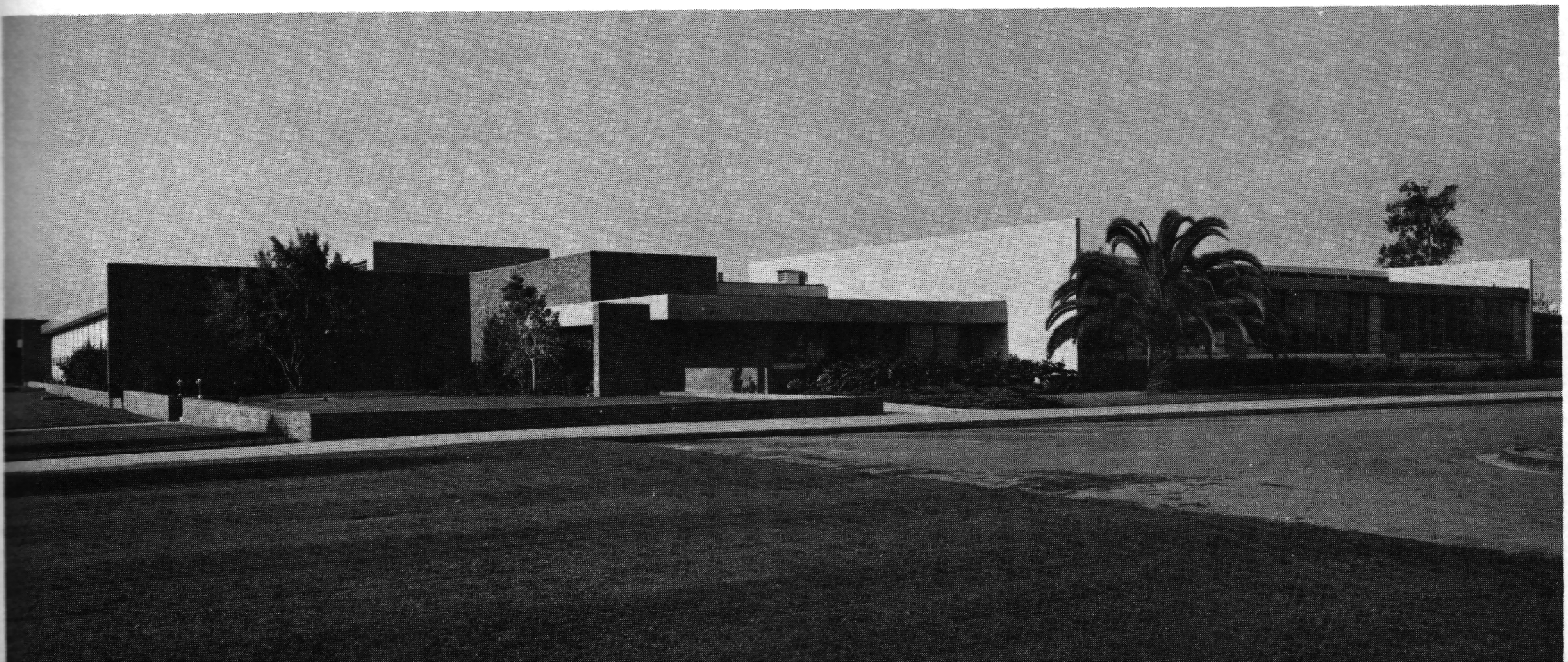


View inside courtyard formed by physics, chemistry, and life sciences departments looking towards physics wing.


PREP RM
OFF.
SUPPLY RM
INST RM
BAL RM
LABORATORY
STORAGE RM
STOR
LECTURE ROOM
LECTURE ROOMS
SUPPLY ROOM
BALANCE ROOM
PREPARATION RM
CHEMISTRY LABORATORIES
OFFICES
LOBBY
M
W
SHELTER
CHEMISTRY
ANATOMY AND PHYSIOLOGY
BIOLOGY
PREP ROOMS
STORAGE
ZOOLOGY
BOTANY AND BACTERIOLOGY
MUSEUM
CONSERVATORY
PATIO
MECH EQUIP
SUPPLY
PREP ROOM
MECHANICAL EQUIPMENT
CHEMISTRY & PHYSICS
PHYSICS
DK RM
STOCK RM
DEMONSTRATION EQUIPMENT
OPTICS
DEMONSTRATION ROOM
CONFERENCE ROOM
PHYSICS LABORATORIES
NORTH
0 10 FEET 50


MANHATTAN BEACH BOULEVARD
MAINTENANCE SHOPS
MAINTENANCE YARD
MAINTENANCE SHOPS
PARKING
APPLIED ARTS
PARKING
MEN'S ATHLETIC FIELD
SHOPS
SHOP
LIFE SCIENCE
PHYSICS
CHEMISTRY
CLASSROOMS
AUDIO VISUAL
CLASSROOMS
CLASSROOMS
CLASSROOMS
OFFICES
BOOK STORE
LOUNGE
LIBRARY
ADMINISTRATION
CLASSROOMS
CAMPUS CENTER
CRENSHAW BOULEVARD
FIELD HOUSE
TRACK AND FIELD
MEN'S GYMNASIUM
AUDITORIUM
COMMERCE
ART
FOOTBALL STADIUM
PUBLIC TOILET
TICKETS
SWIMMING POOLS
LITTLE THEATER
MUSIC
VOLLEY BALL COURTS
TENNIS COURTS
WOMEN'S GYMNASIUM
HUMANITIES
PARKING
PARKING
BASKET BALL COURTS
WOMEN'S ATHLETIC FIELD
REDONDO BEACH BOULEVARD
NORTH
0
100
FEET
300

View of the physics, chemistry, and life sciences group from Manhattan Beach Boulevard on the north.



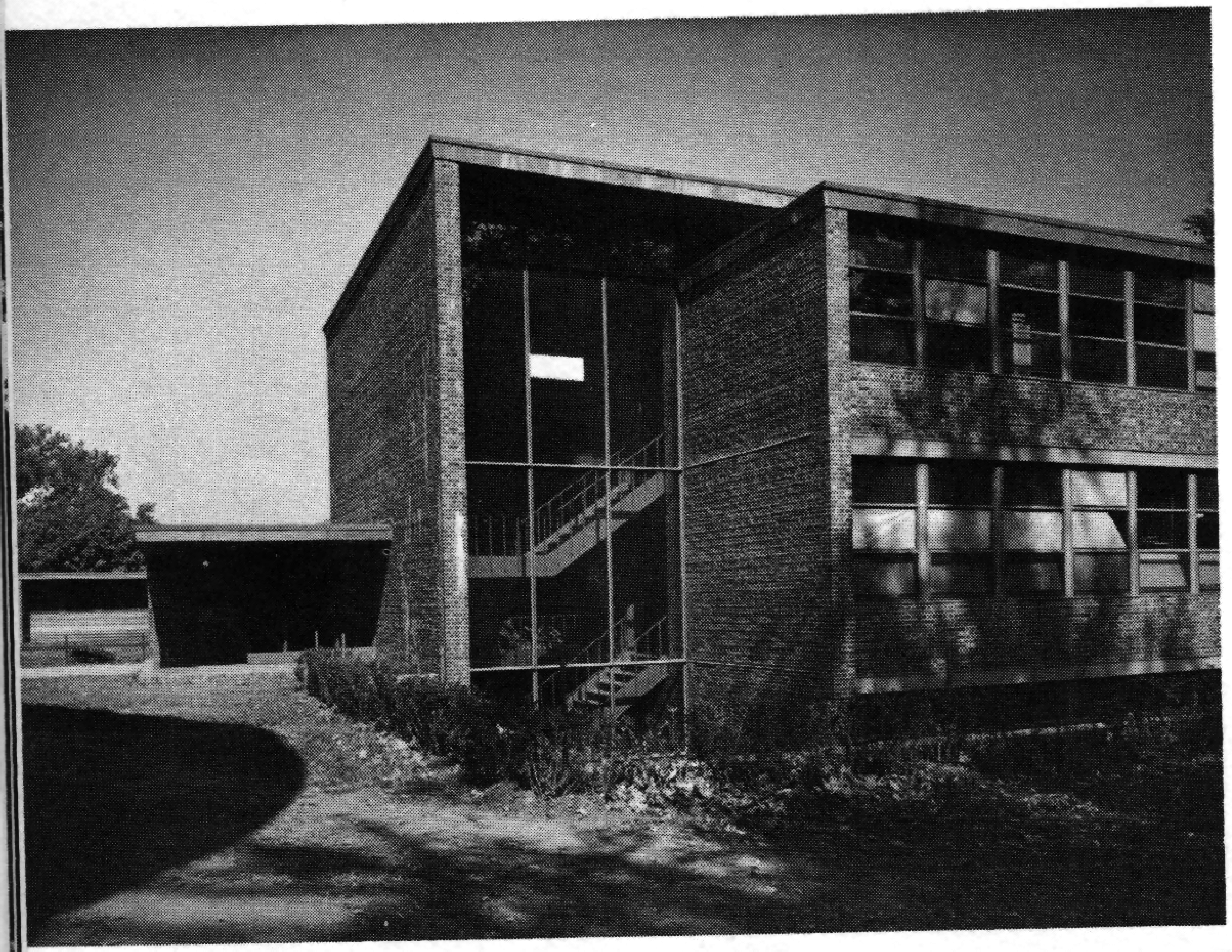
20.

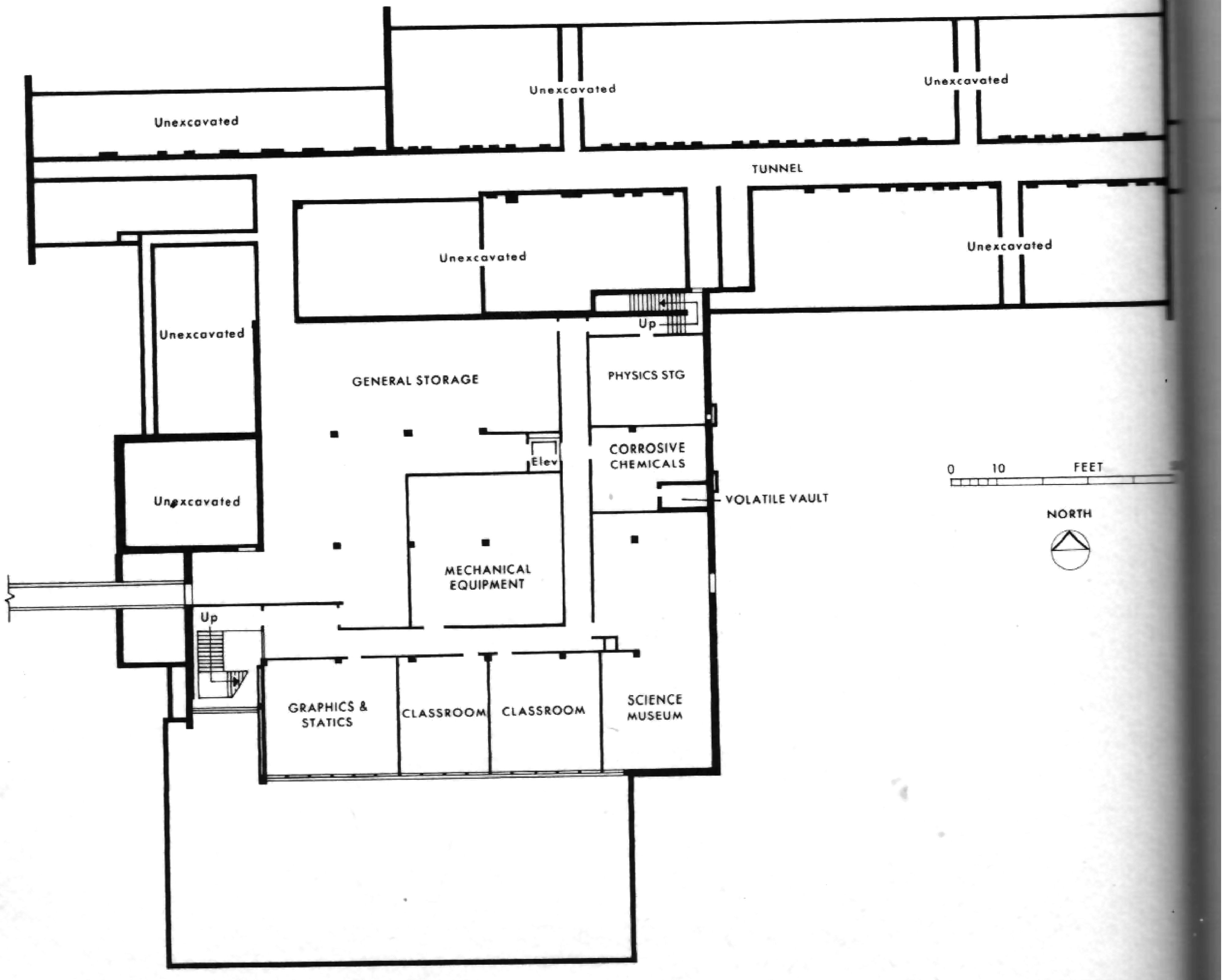
Science Building
Grinnell College
Grinnell, Iowa

Architects:	Brooks and Borg Des Moines, Iowa
Completed:	Summer 1952
Gross Area of Building:	49,170 sq. ft.
Total Cost of Building:	$1,000,000*
Air Conditioning:	Ducts designed in anticipation of future air conditioning

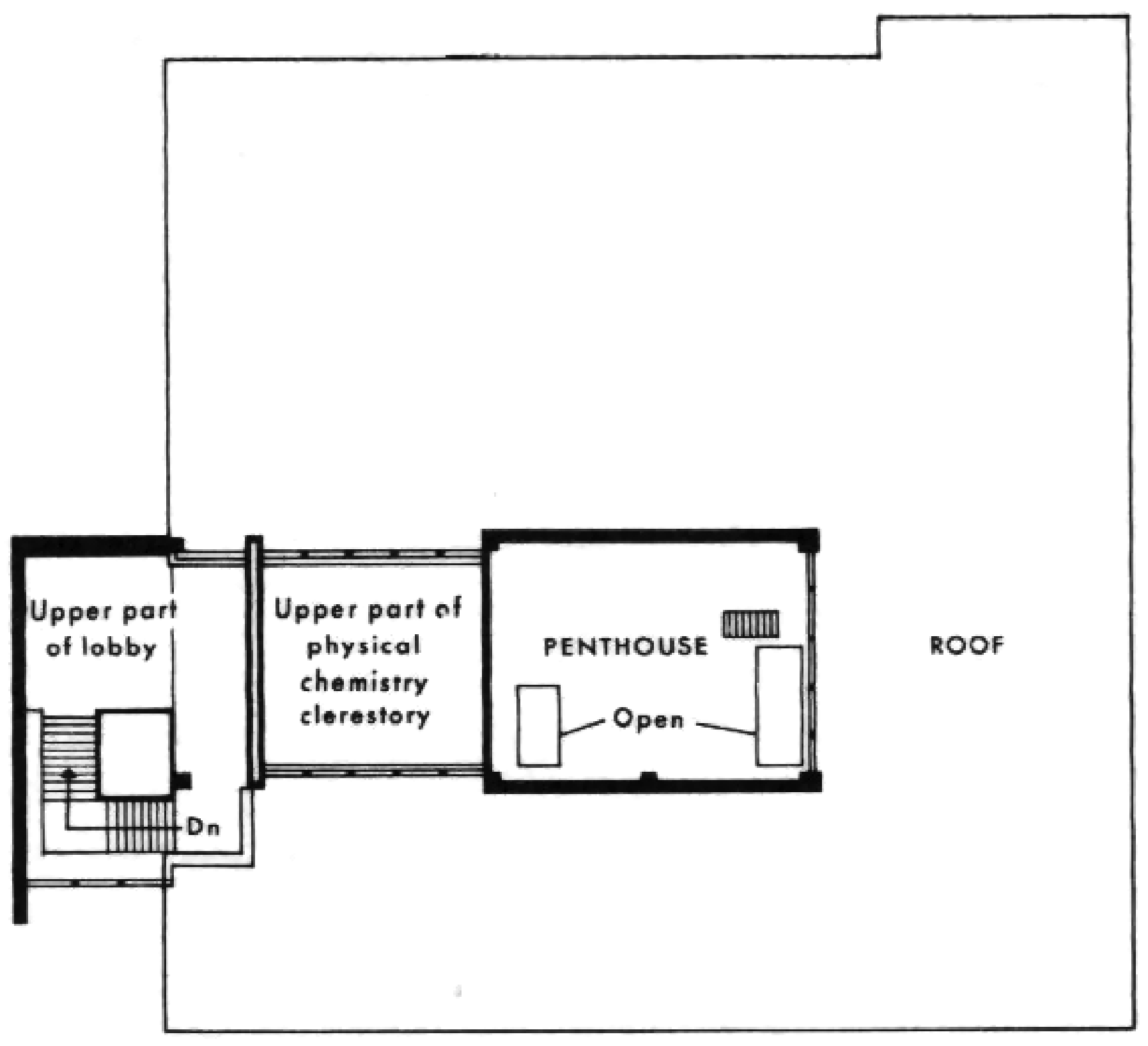
* Includes heating, ventilating, air conditioning ducts, electrical and mechanical services, and laboratory furniture.

Exterior of building with main entrance at left and areaway in foreground.



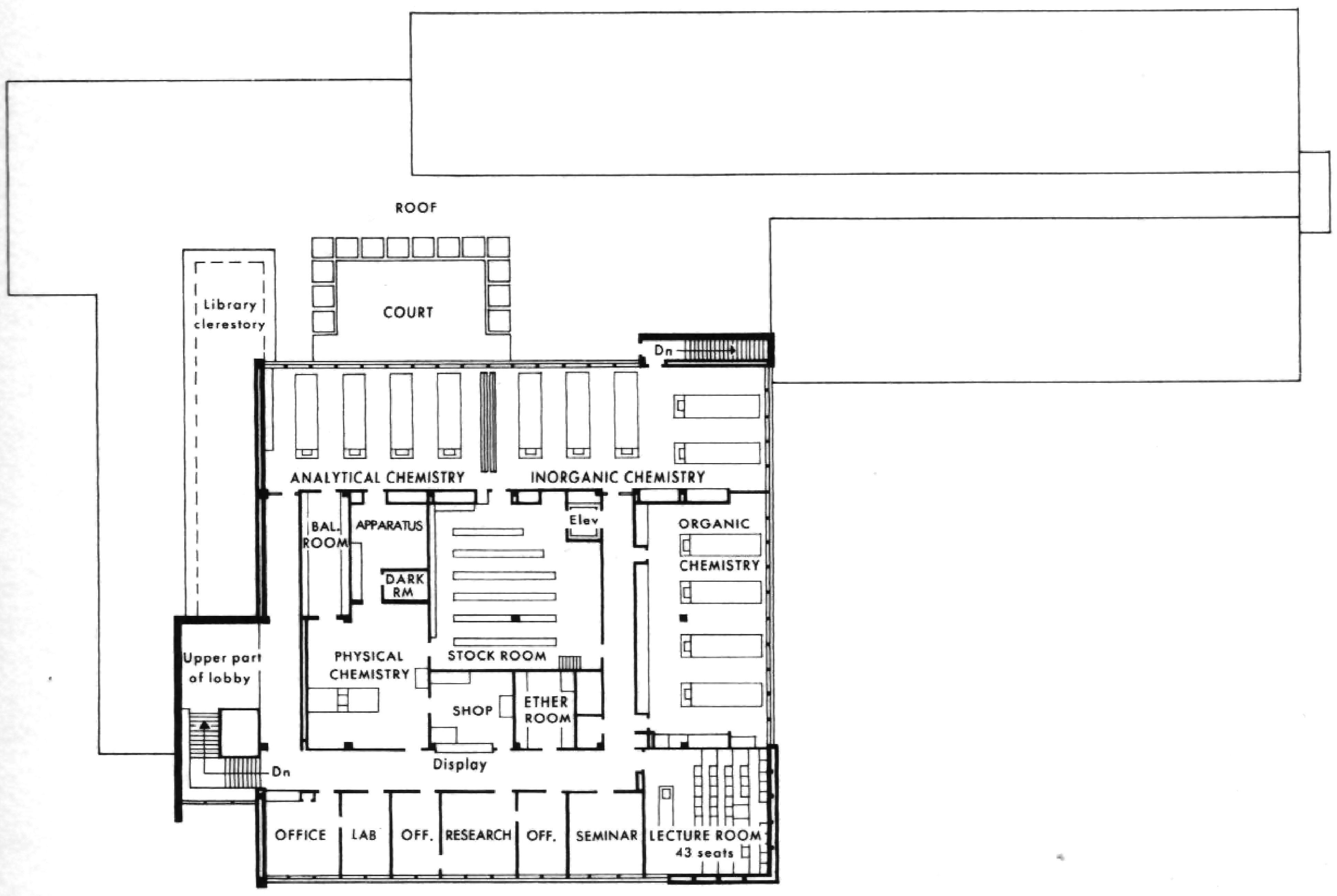

Unexcavated
Unexcavated
Unexcavated
TUNNEL
Unexcavated
Unexcavated
Unexcavated
Up
GENERAL STORAGE
PHYSICS STG
CORROSIVE CHEMICALS
Elev
VOLATILE VAULT
Unexcavated
MECHANICAL EQUIPMENT
Up
GRAPHICS & STATICS
CLASSROOM
CLASSROOM
SCIENCE MUSEUM
0
10
FEET
NORTH

BASEMENT FLOOR PLAN

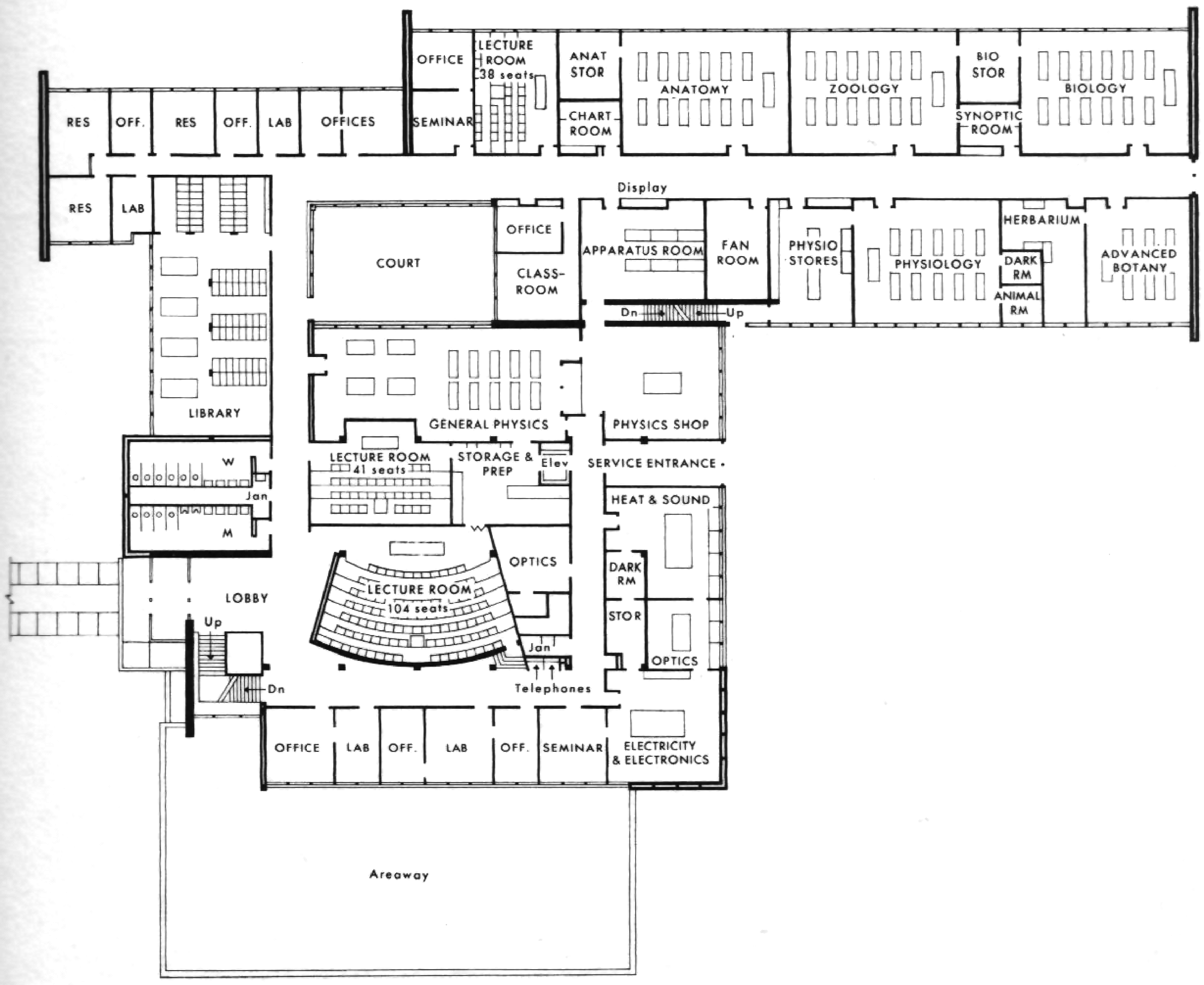

Upper part of lobby
Dn
Upper part of physical chemistry clerestory
PENTHOUSE
Open
ROOF

PENTHOUSE AND ROOF PLAN

View of secondary entrance to physics and chemistry departments with herbarium for botany department. One-story wing on right houses life sciences.


ROOF
COURT
Library clerestory
Dn
ANALYTICAL CHEMISTRY
INORGANIC CHEMISTRY
BAL. ROOM
APPARATUS
Elev
ORGANIC CHEMISTRY
DARK RM
PHYSICAL CHEMISTRY
STOCK ROOM
SHOP
ETHER ROOM
Upper part of lobby
Dn
Display
OFFICE
LAB
OFF.
RESEARCH
OFF.
SEMINAR
LECTURE ROOM 43 seats

SECOND FLOOR PLAN


RES
OFF.
RES
OFF.
LAB
OFFICES
OFFICE
SEMINAR
LECTURE ROOM 38 seats
ANAT STOR
CHART ROOM
ANATOMY
ZOOLOGY
BIO STOR
SYNOPTIC ROOM
BIOLOGY
RES
LAB
Display
COURT
OFFICE
CLASS-ROOM
APPARATUS ROOM
FAN ROOM
PHYSIO STORES
PHYSIOLOGY
HERBARIUM
DARK RM
ANIMAL RM
ADVANCED BOTANY
Dn
Up
LIBRARY
GENERAL PHYSICS
PHYSICS SHOP
LECTURE ROOM 41 seats
STORAGE & PREP
Elev
SERVICE ENTRANCE
W
Jan
M
HEAT & SOUND
OPTICS
DARK RM
LOBBY
LECTURE ROOM 104 seats
STOR
Up
Jan
OPTICS
Dn
Telephones
OFFICE
LAB
OFF.
LAB
OFF.
SEMINAR
ELECTRICITY & ELECTRONICS
Areaway

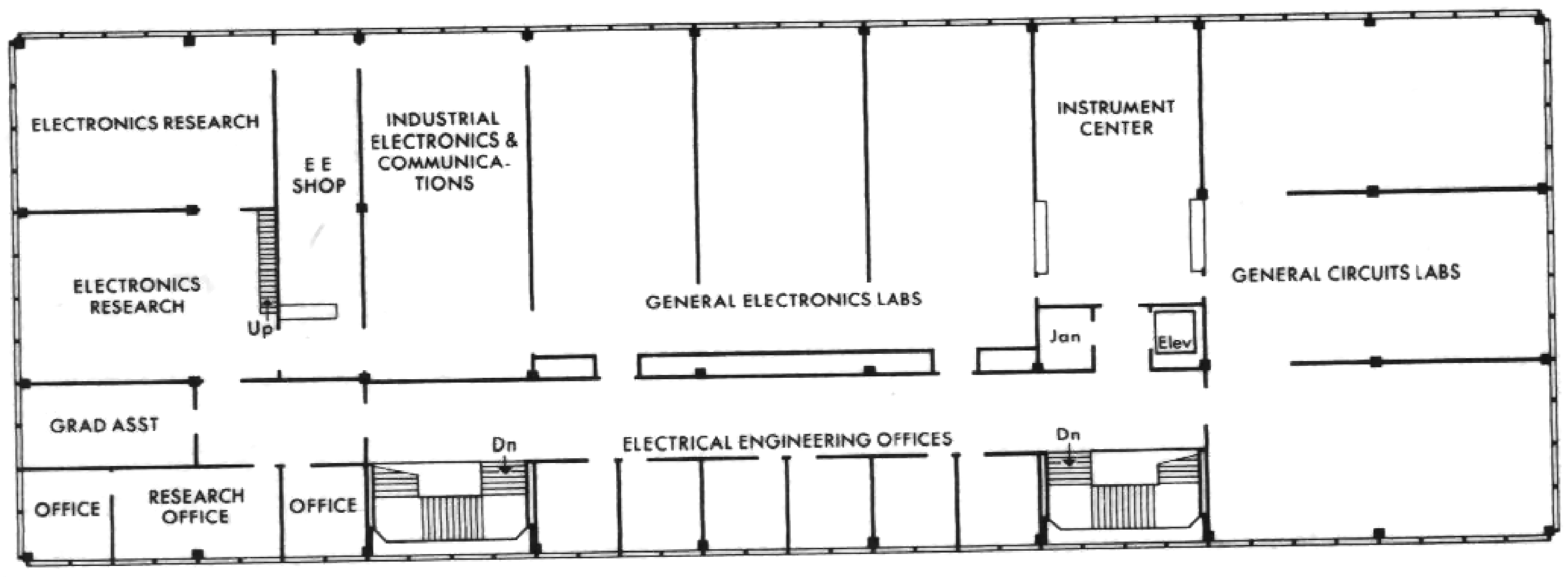
FIRST FLOOR PLAN

21.

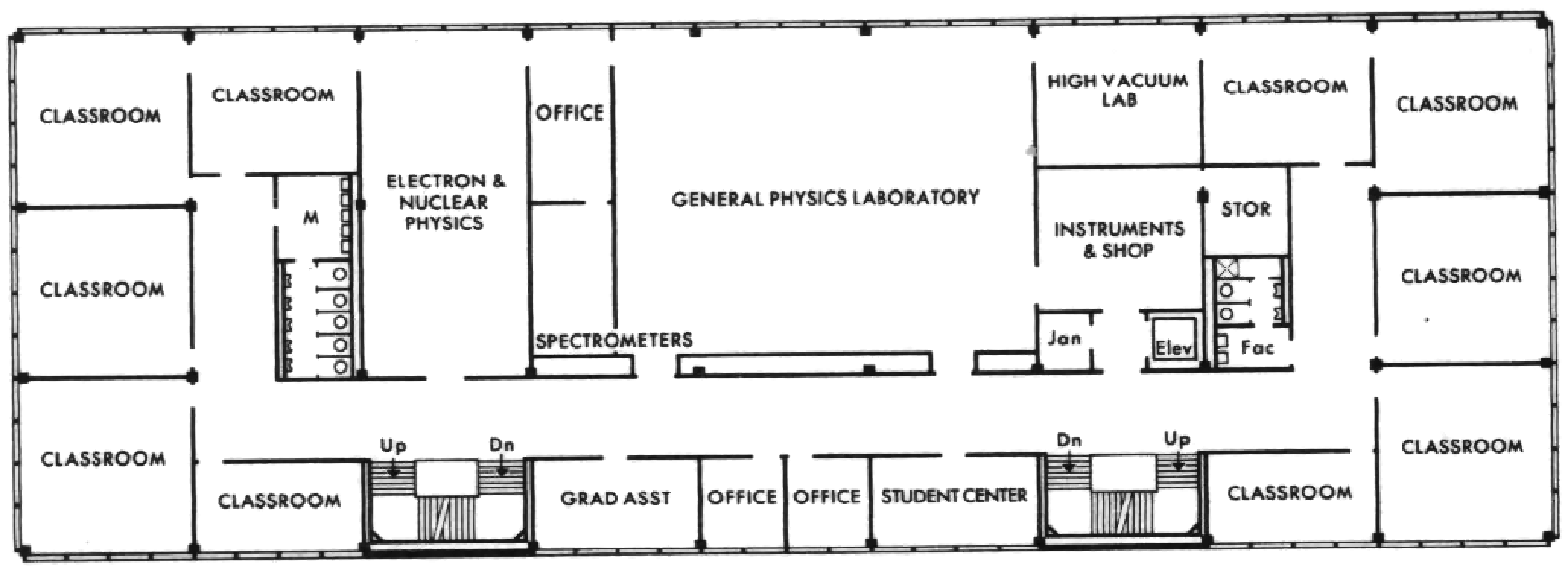
Siegel Hall
Illinois Institute of Technology
Chicago, Illinois

Architects:	Ludwig Mies van der Rohe Chicago, Illinois
Completed:	March 1958
Gross Area of Building:	61,512 sq. ft.
Total Cost of Building:	$1,257,103*
Air Conditioning:	50% of the building

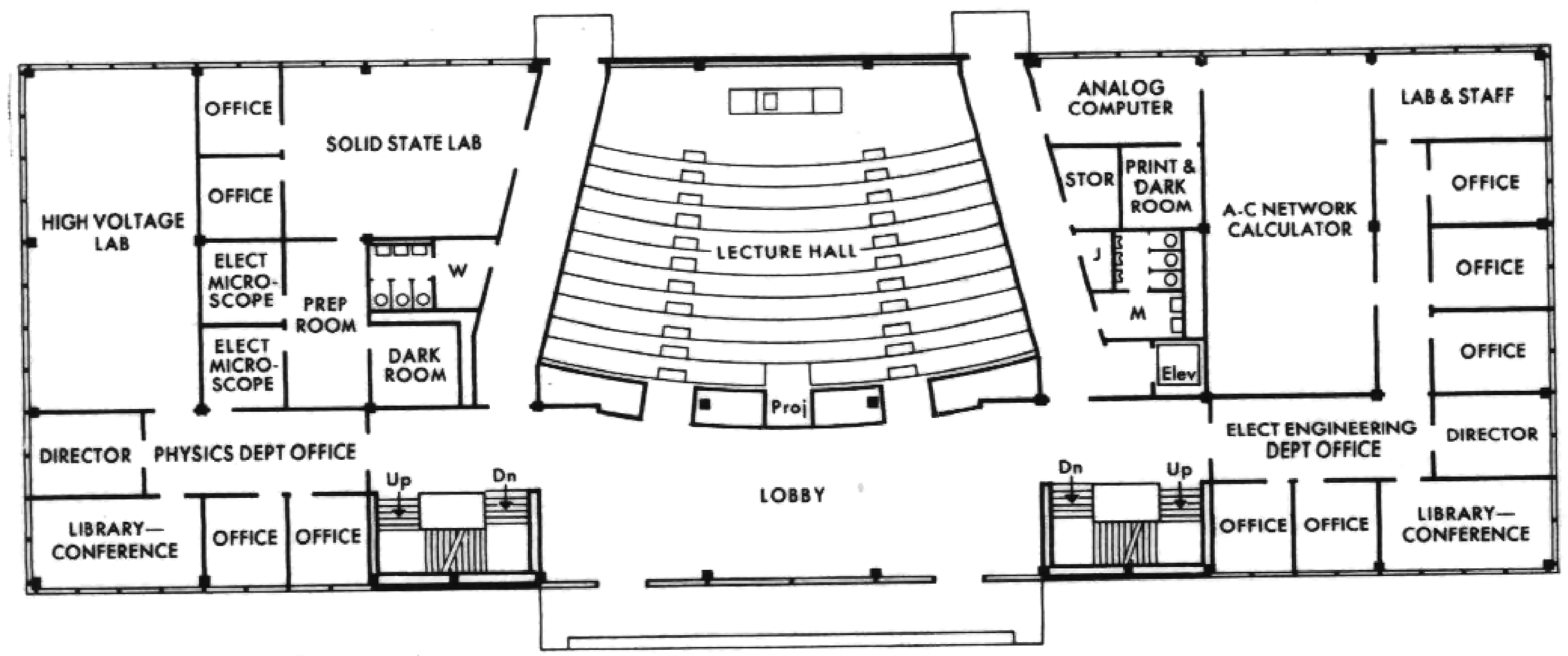
* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.


ELECTRONICS RESEARCH
E E SHOP
INDUSTRIAL ELECTRONICS & COMMUNICATIONS
INSTRUMENT CENTER
ELECTRONICS RESEARCH
Up
GENERAL ELECTRONICS LABS
Jan
Elev
GENERAL CIRCUITS LABS
GRAD ASST
Dn
ELECTRICAL ENGINEERING OFFICES
Dn
OFFICE
RESEARCH OFFICE
OFFICE

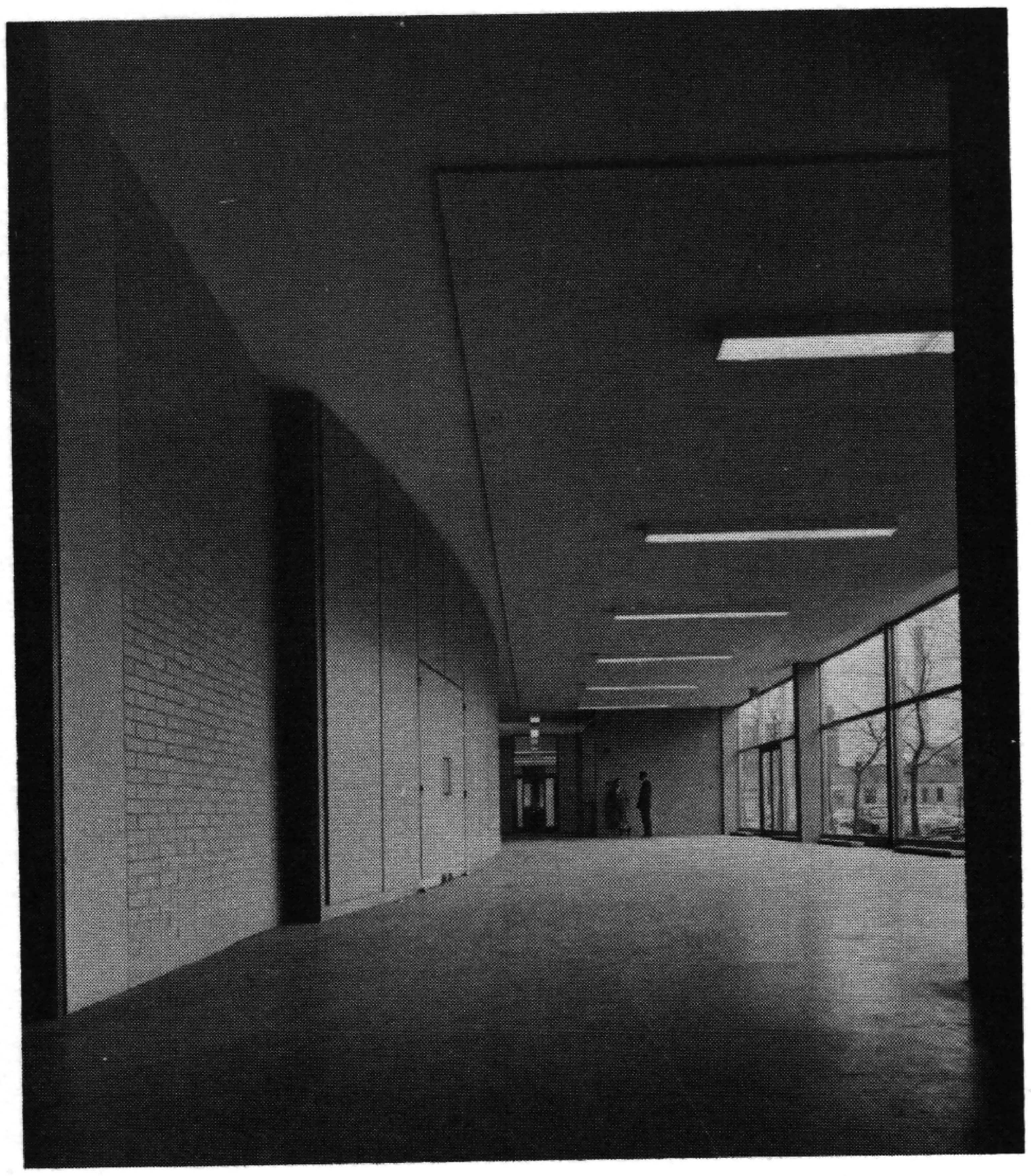
THIRD FLOOR PLAN


CLASSROOM
CLASSROOM
OFFICE
HIGH VACUUM LAB
CLASSROOM
CLASSROOM
ELECTRON & NUCLEAR PHYSICS
M
GENERAL PHYSICS LABORATORY
INSTRUMENTS & SHOP
STOR
CLASSROOM
CLASSROOM
SPECTROMETERS
Jan
Elev
Fac
CLASSROOM
Up
Dn
Dn
Up
CLASSROOM
CLASSROOM
GRAD ASST
OFFICE
OFFICE
STUDENT CENTER
CLASSROOM
CLASSROOM

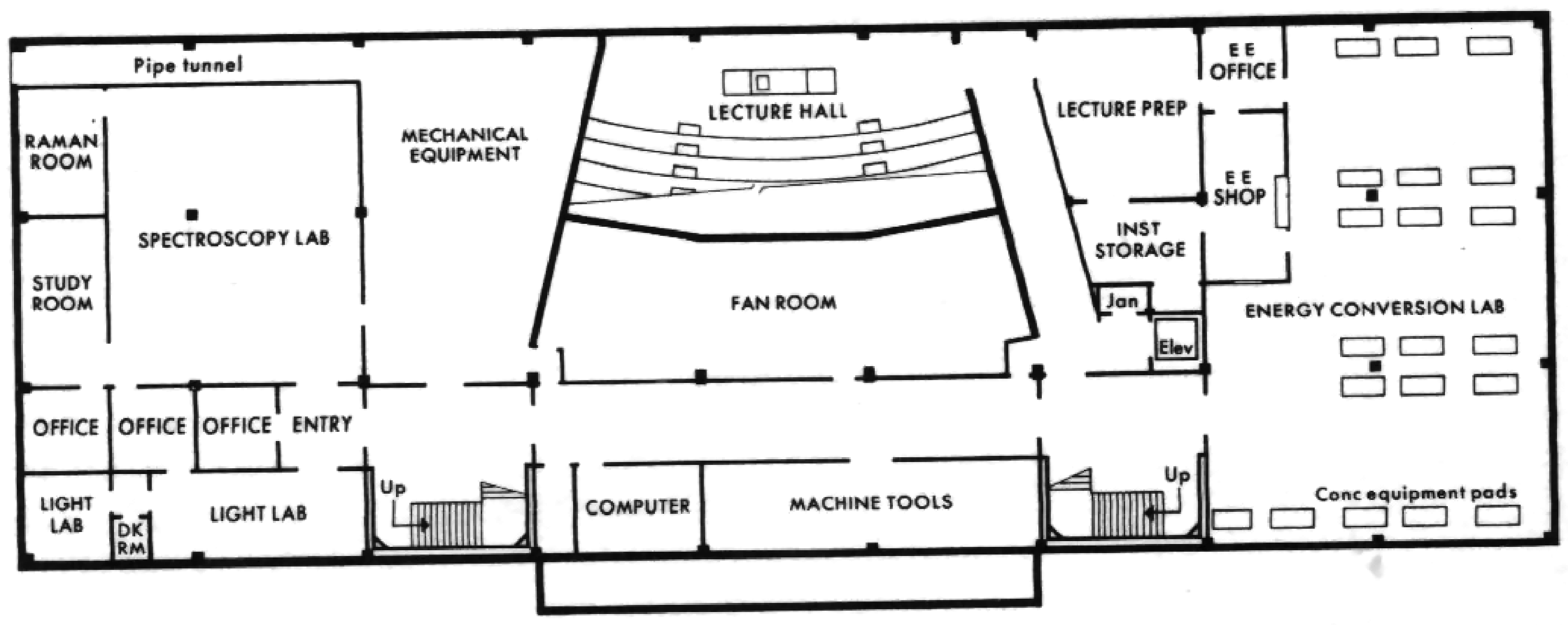
SECOND FLOOR PLAN


OFFICE
SOLID STATE LAB
ANALOG COMPUTER
LAB & STAFF
OFFICE
HIGH VOLTAGE LAB
STOR
PRINT & DARK ROOM
A-C NETWORK CALCULATOR
OFFICE
W
LECTURE HALL
J
OFFICE
ELECT MICRO-SCOPE
PREP ROOM
M
ELECT MICRO-SCOPE
DARK ROOM
Elev
OFFICE
Proj
DIRECTOR
PHYSICS DEPT OFFICE
ELECT ENGINEERING DEPT OFFICE
DIRECTOR
Up
Dn
LOBBY
Dn
Up
LIBRARY—CONFERENCE
OFFICE
OFFICE
OFFICE
OFFICE
LIBRARY—CONFERENCE

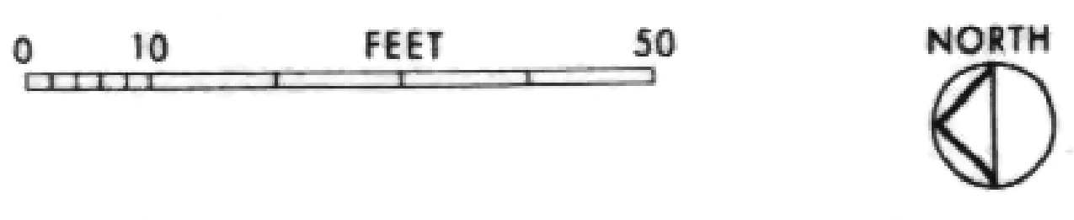
FIRST FLOOR PLAN



View of lobby showing polygonal "curved" wall which is rear of lecture room. Floor is terrazzo; ceiling has acoustical tile panel. Main entrance facade of building is shown on facing page.


Pipe tunnel
E E OFFICE
RAMAN ROOM
MECHANICAL EQUIPMENT
LECTURE HALL
LECTURE PREP
E E SHOP
SPECTROSCOPY LAB
INST STORAGE
STUDY ROOM
FAN ROOM
Jan
Elev
ENERGY CONVERSION LAB
OFFICE
OFFICE
OFFICE
ENTRY
Up
Up
LIGHT LAB
DK RM
LIGHT LAB
COMPUTER
MACHINE TOOLS
Conc equipment pads

BASEMENT FLOOR PLAN

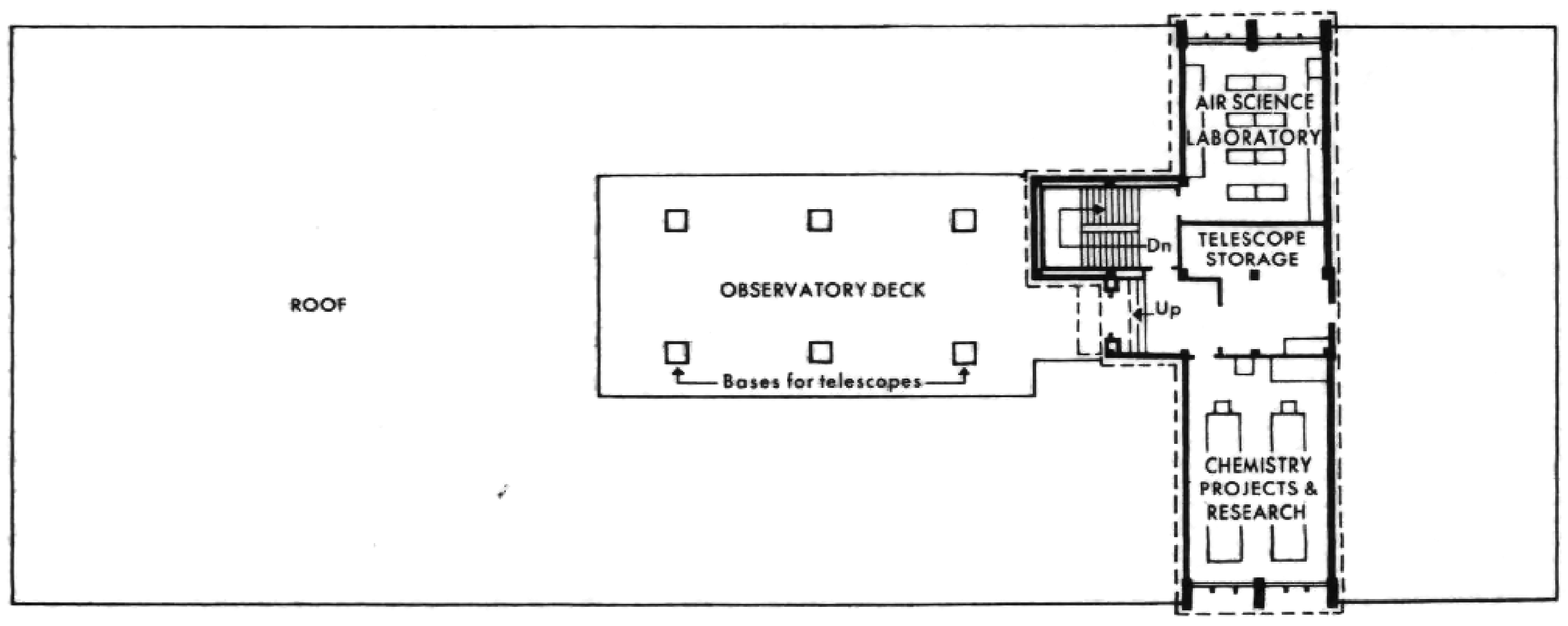

0
10
FEET
50
NORTH

22.

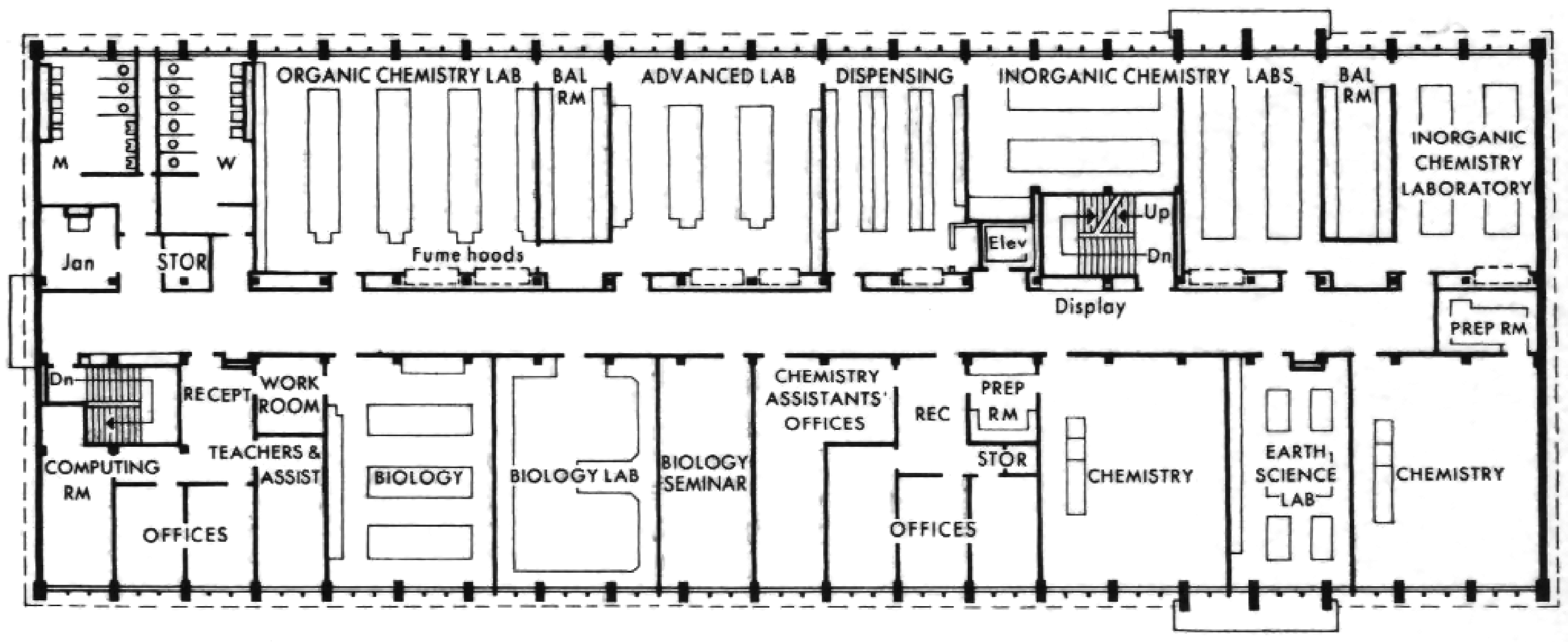
Science Hall
Kansas State Teacher's College
Emporia, Kansas

Architects:	State Architect Topeka, Kansas
Completed:	1959
Gross Area of Building:	45,200 sq. ft.
Total Cost of Building:	$1,100,000*
Air Conditioning:	A central water chilling unit is located at the college power plant (1200 ft. distant). Chilled water at approximately 50° F is circulated via tunnel in 6" pipes. Central unit also serves student union and mens' dormitory.

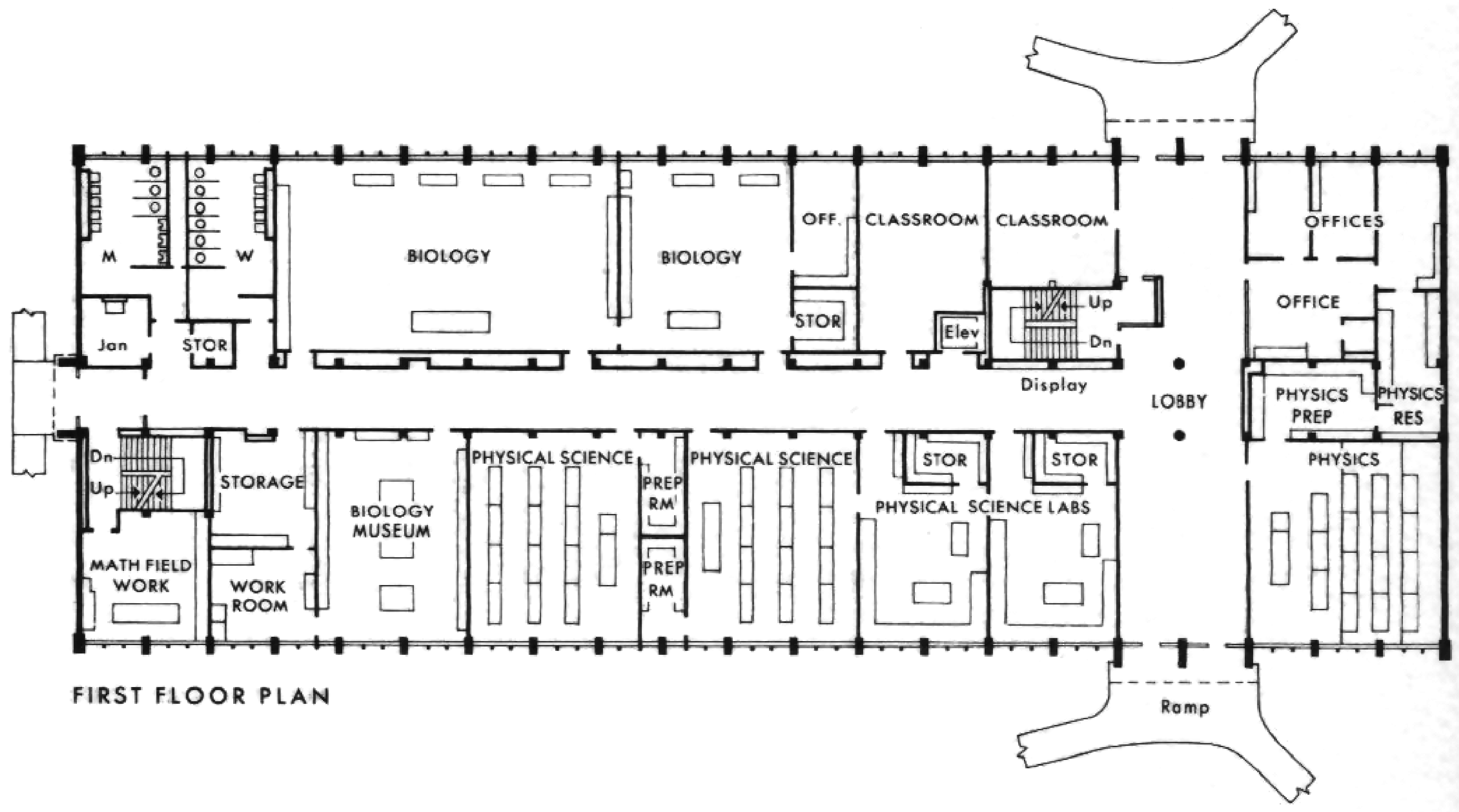
* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.


ROOF
OBSERVATORY DECK
Bases for telescopes
AIR SCIENCE LABORATORY
TELESCOPE STORAGE
Dn
Up
CHEMISTRY PROJECTS & RESEARCH

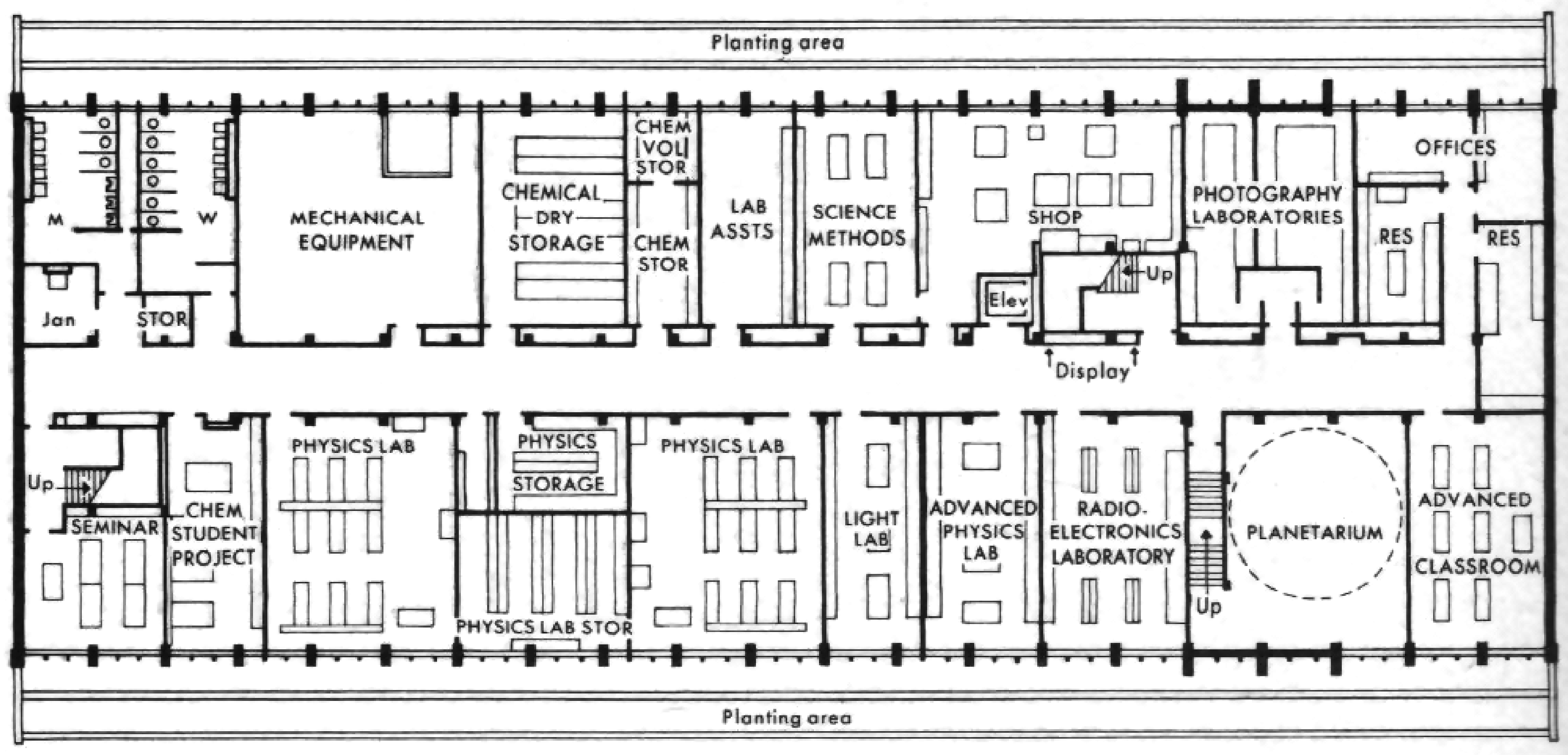
PENTHOUSE PLAN


ORGANIC CHEMISTRY LAB
BAL RM
ADVANCED LAB
DISPENSING
INORGANIC CHEMISTRY LABS
BAL RM
INORGANIC CHEMISTRY LABORATORY
M
W
Jan
STOR
Fume hoods
Elev
Up
Dn
Display
PREP RM
Dn
RECEPT
WORK ROOM
TEACHERS & ASSIST
COMPUTING RM
OFFICES
BIOLOGY
BIOLOGY LAB
BIOLOGY SEMINAR
CHEMISTRY ASSISTANTS' OFFICES
REC
PREP RM
STOR
OFFICES
CHEMISTRY
EARTH SCIENCE LAB
CHEMISTRY

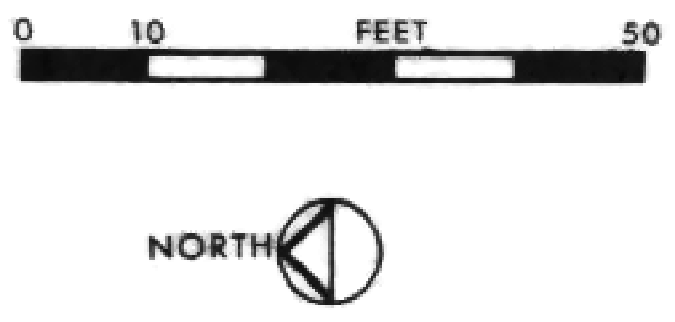
SECOND FLOOR PLAN

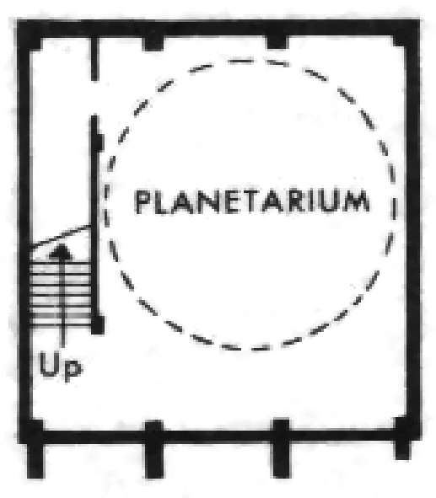

M
W
Jan
STOR
BIOLOGY
BIOLOGY
OFF.
CLASSROOM
CLASSROOM
STOR
Elev
Up
Dn
Display
LOBBY
OFFICES
OFFICE
PHYSICS PREP
PHYSICS RES
PHYSICS
Dn
Up
STORAGE
MATH FIELD WORK
WORK ROOM
BIOLOGY MUSEUM
PHYSICAL SCIENCE
PREP RM
PREP RM
PHYSICAL SCIENCE
STOR
STOR
PHYSICAL SCIENCE LABS
Ramp

FIRST FLOOR PLAN


Planting area
M
W
Jan
STOR
MECHANICAL EQUIPMENT
CHEMICAL DRY STORAGE
CHEM VOL STOR
CHEM STOR
LAB ASSTS
SCIENCE METHODS
SHOP
Elev
Up
Display
PHOTOGRAPHY LABORATORIES
OFFICES
RES
RES
Up
SEMINAR
CHEM STUDENT PROJECT
PHYSICS LAB
PHYSICS STORAGE
PHYSICS LAB
PHYSICS LAB STOR
LIGHT LAB
ADVANCED PHYSICS LAB
RADIO-ELECTRONICS LABORATORY
PLANETARIUM
Up
ADVANCED CLASSROOM
Planting area

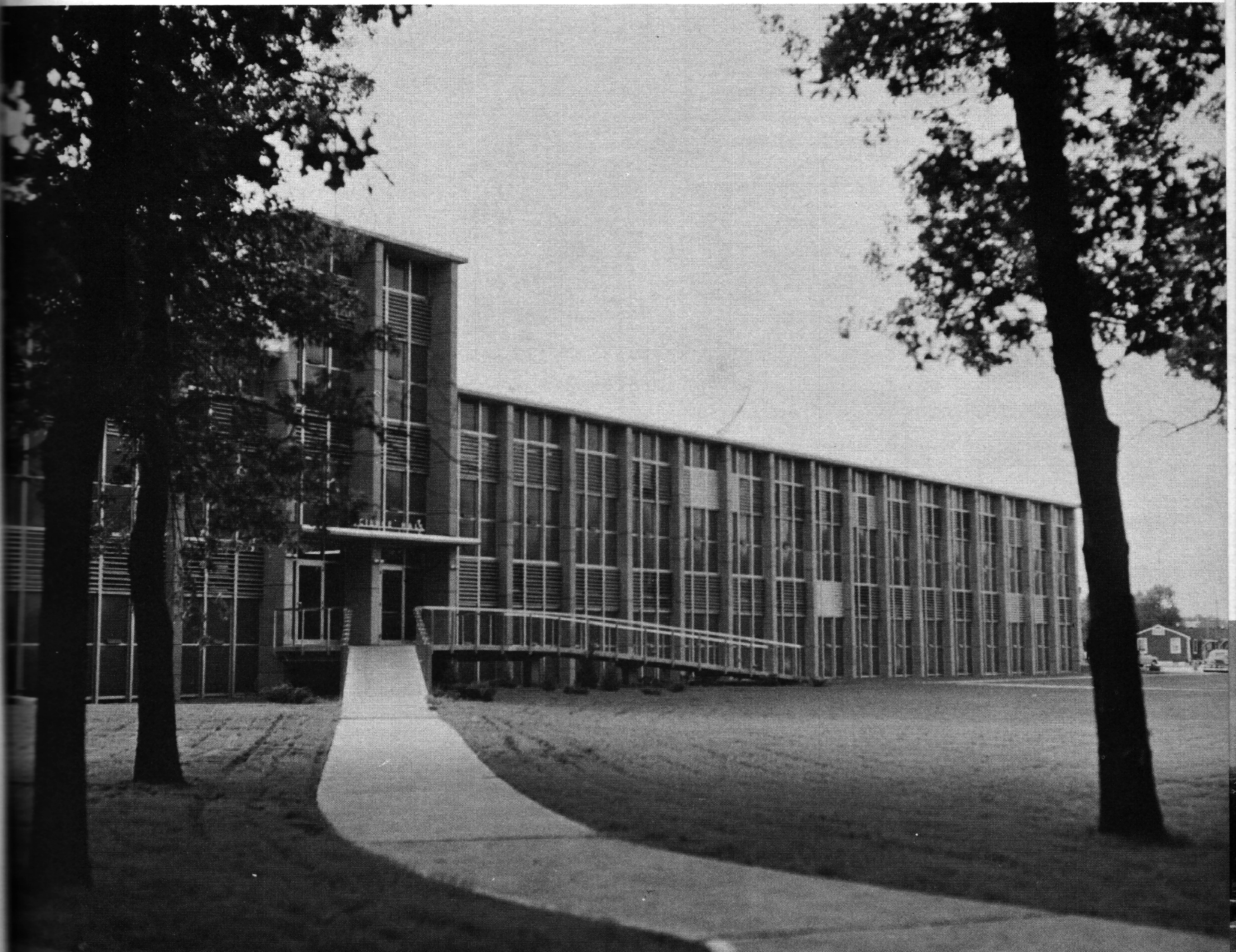
GROUND FLOOR PLAN


0
10
FEET
50
NORTH


PLANETARIUM
Up

PLAN AT LOWER LEVEL

East entrance showing concrete ramp with aluminum handrail. Exterior louvers on the window-wall can be adjusted from interior.

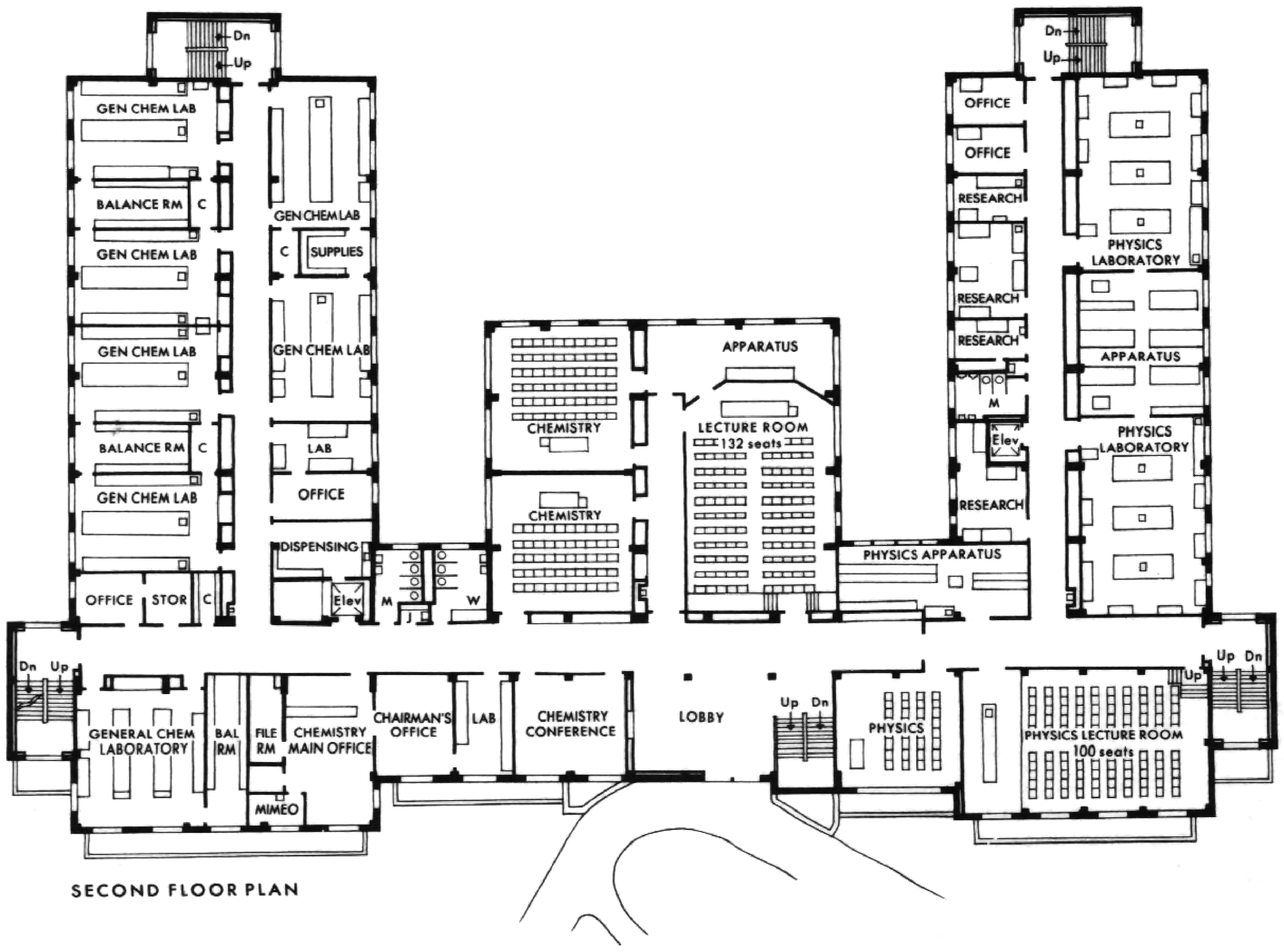


23.

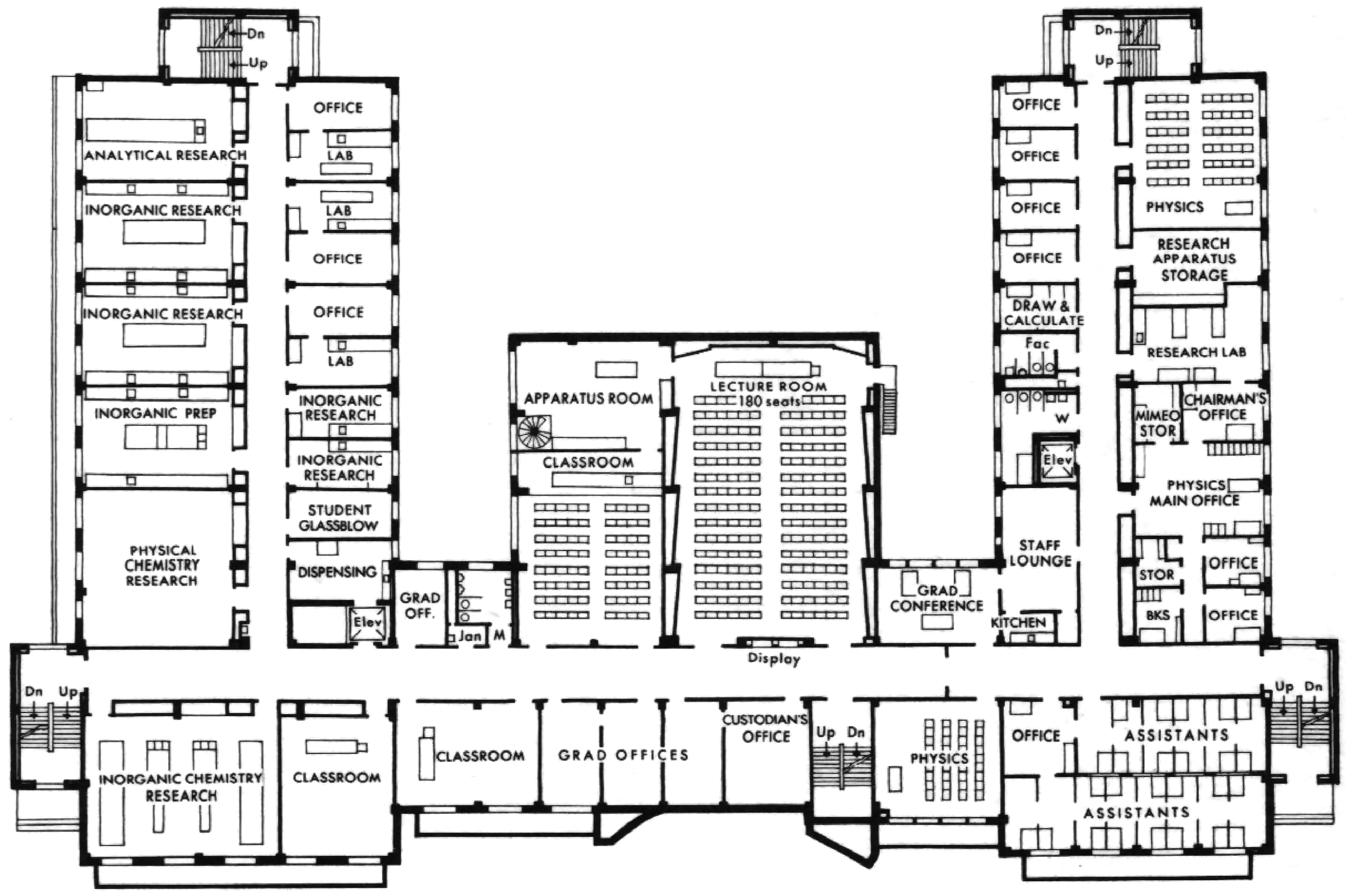
Malott Hall
The University of Kansas
Lawrence, Kansas

Architects:	Charles Marshall Topeka, Kansas
Completed:	1954
Gross Area of Building:	165,000 sq. ft.
Total Cost of Building:	$3,500,000*
Air Conditioning:	Certain research rooms plus departmental office

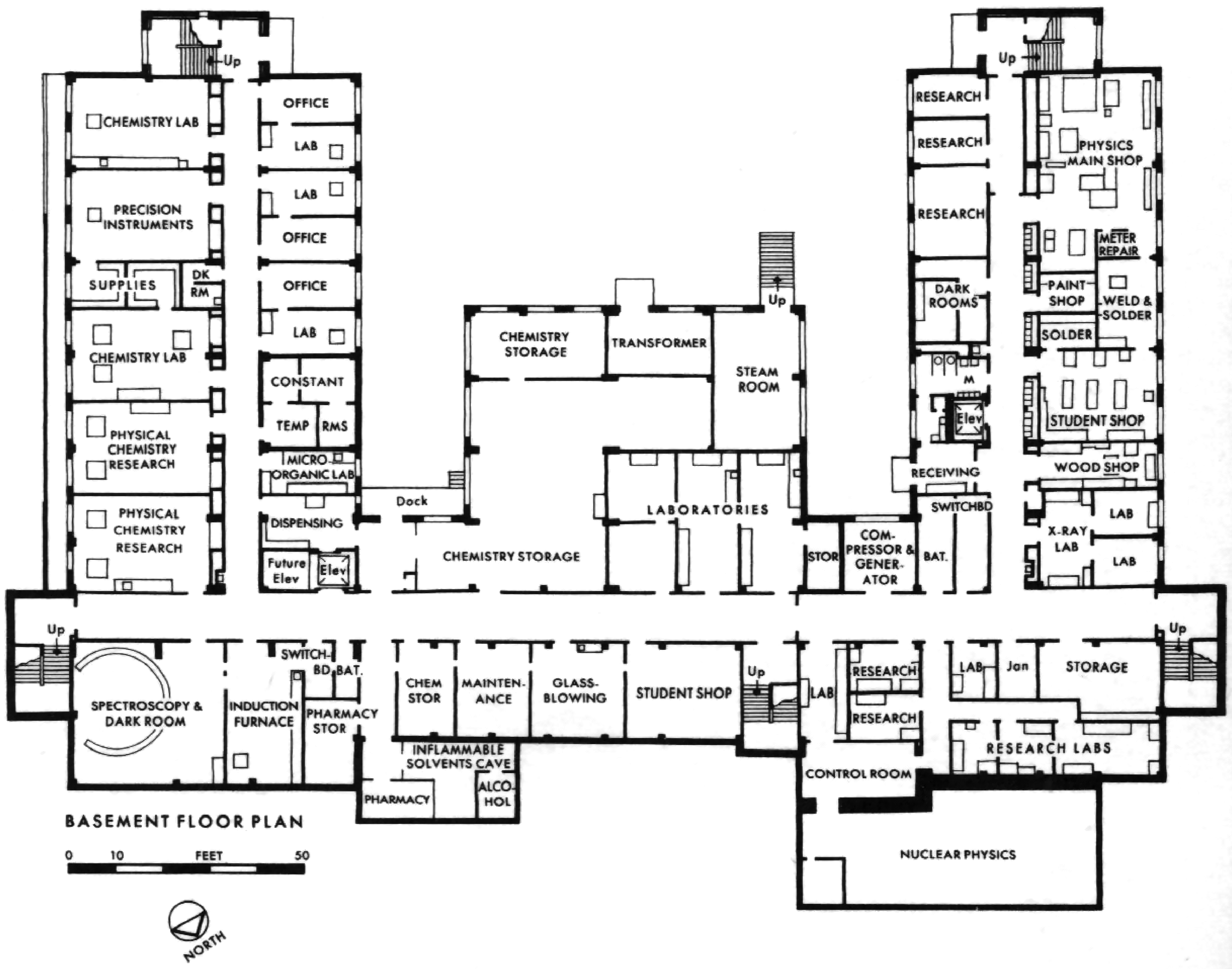
* Includes heating, ventilating, air conditioning (partial), electrical and mechanical services, and laboratory furniture.


Dn
Up
GEN CHEM LAB
BALANCE RM
C
GEN CHEM LAB
GEN CHEM LAB
BALANCE RM
C
GEN CHEM LAB
OFFICE
STOR
C
GEN CHEM LAB
C
SUPPLIES
GEN CHEM LAB
LAB
OFFICE
DISPENSING
Elev
M
W
CHEMISTRY
CHEMISTRY
APPARATUS
LECTURE ROOM
132 seats
PHYSICS APPARATUS
OFFICE
OFFICE
RESEARCH
RESEARCH
RESEARCH
M
Elev
RESEARCH
PHYSICS LABORATORY
APPARATUS
PHYSICS LABORATORY
Dn
Up
GENERAL CHEM LABORATORY
BAL RM
FILE RM
CHEMISTRY MAIN OFFICE
MIMEO
CHAIRMAN'S OFFICE
LAB
CHEMISTRY CONFERENCE
LOBBY
Up
Dn
PHYSICS
PHYSICS LECTURE ROOM
100 seats
Up
Dn

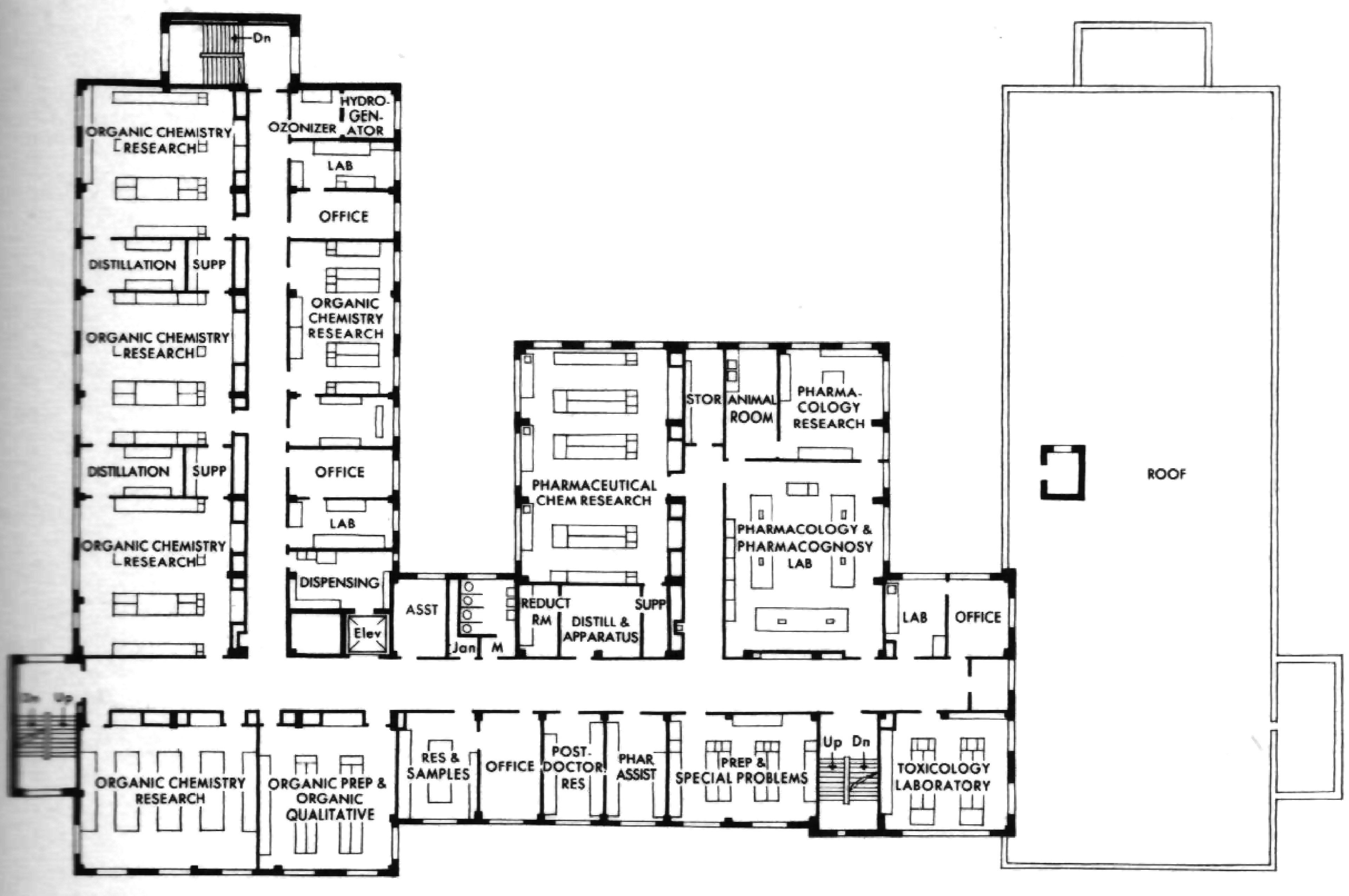
SECOND FLOOR PLAN


Dn
Up
ANALYTICAL RESEARCH
INORGANIC RESEARCH
INORGANIC RESEARCH
INORGANIC PREP
PHYSICAL CHEMISTRY RESEARCH
OFFICE
LAB
LAB
OFFICE
OFFICE
LAB
INORGANIC RESEARCH
INORGANIC RESEARCH
STUDENT GLASSBLOW
DISPENSING
Elev
GRAD OFF.
Jan
M
APPARATUS ROOM
CLASSROOM
LECTURE ROOM
180 seats
Display
GRAD CONFERENCE
OFFICE
OFFICE
OFFICE
OFFICE
DRAW & CALCULATE
Fac
W
Elev
STAFF LOUNGE
KITCHEN
PHYSICS
RESEARCH APPARATUS STORAGE
RESEARCH LAB
MIMEO STOR
CHAIRMAN'S OFFICE
PHYSICS MAIN OFFICE
STOR
OFFICE
BKS
OFFICE
Dn
Up
INORGANIC CHEMISTRY RESEARCH
CLASSROOM
CLASSROOM
GRAD OFFICES
CUSTODIAN'S OFFICE
Up
Dn
PHYSICS
OFFICE
ASSISTANTS
ASSISTANTS
Up
Dn

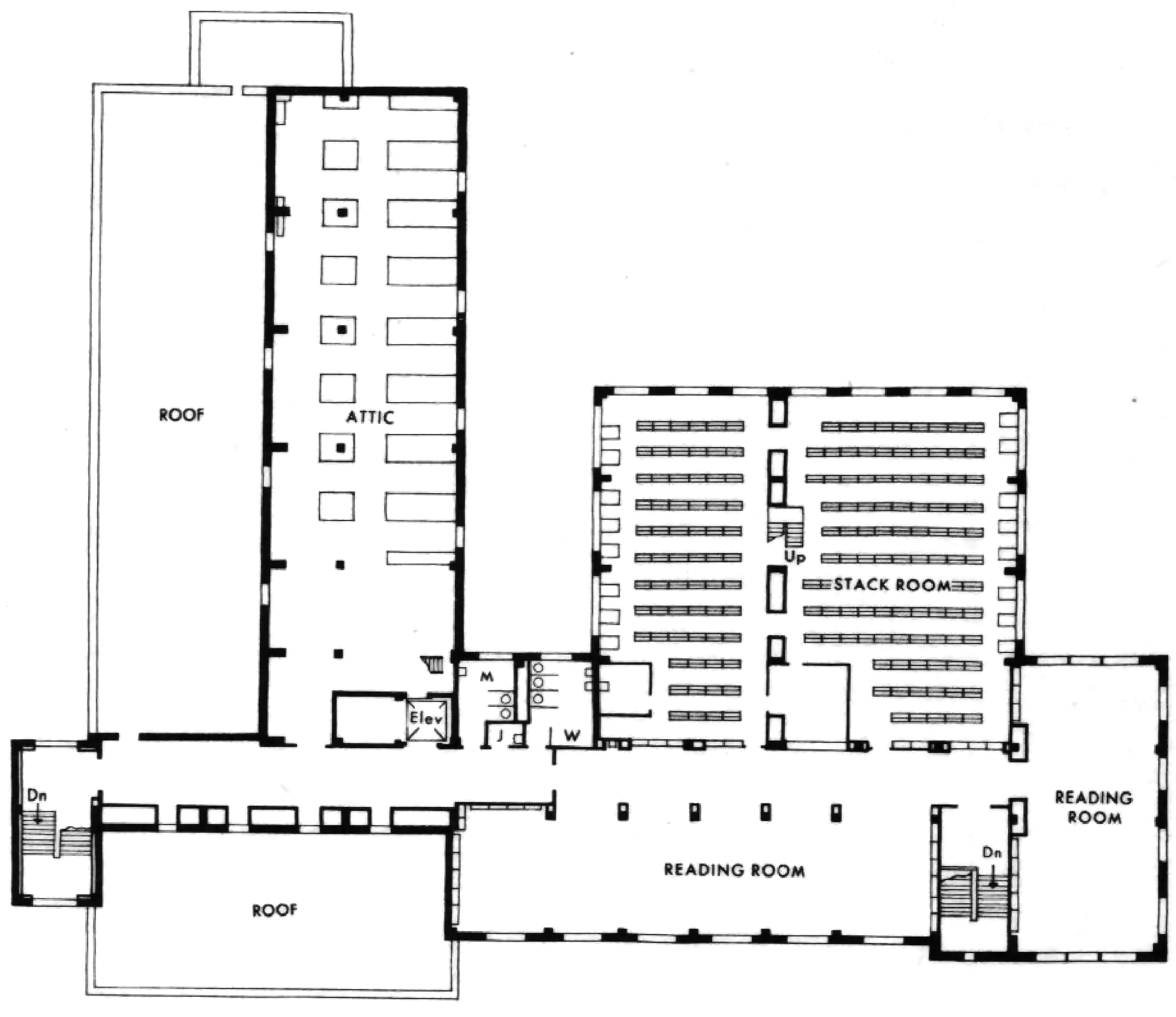
FIRST FLOOR PLAN


Up
CHEMISTRY LAB
PRECISION INSTRUMENTS
SUPPLIES
DK RM
CHEMISTRY LAB
PHYSICAL CHEMISTRY RESEARCH
PHYSICAL CHEMISTRY RESEARCH
OFFICE
LAB
LAB
OFFICE
OFFICE
LAB
CONSTANT
TEMP
RMS
MICRO ORGANIC LAB
DISPENSING
Future Elev
Elev
Dock
CHEMISTRY STORAGE
TRANSFORMER
STEAM ROOM
Up
LABORATORIES
CHEMISTRY STORAGE
STOR
COM-PRESSOR & GENER-ATOR
BAT.
Up
RESEARCH
RESEARCH
RESEARCH
DARK ROOMS
M
Elev
RECEIVING
SWITCHBD
PHYSICS MAIN SHOP
METER REPAIR
PAINT SHOP
WELD & SOLDER
SOLDER
STUDENT SHOP
WOOD SHOP
LAB
X-RAY LAB
LAB
Up
SPECTROSCOPY & DARK ROOM
INDUCTION FURNACE
SWITCH-BD
BAT.
PHARMACY STOR
CHEM STOR
MAINTEN-ANCE
GLASS-BLOWING
STUDENT SHOP
INFLAMMABLE SOLVENTS CAVE
PHARMACY
ALCO-HOL
Up
LAB
RESEARCH
RESEARCH
LAB
Jan
STORAGE
Up
RESEARCH LABS
CONTROL ROOM
NUCLEAR PHYSICS
0
10
FEET
50
NORTH

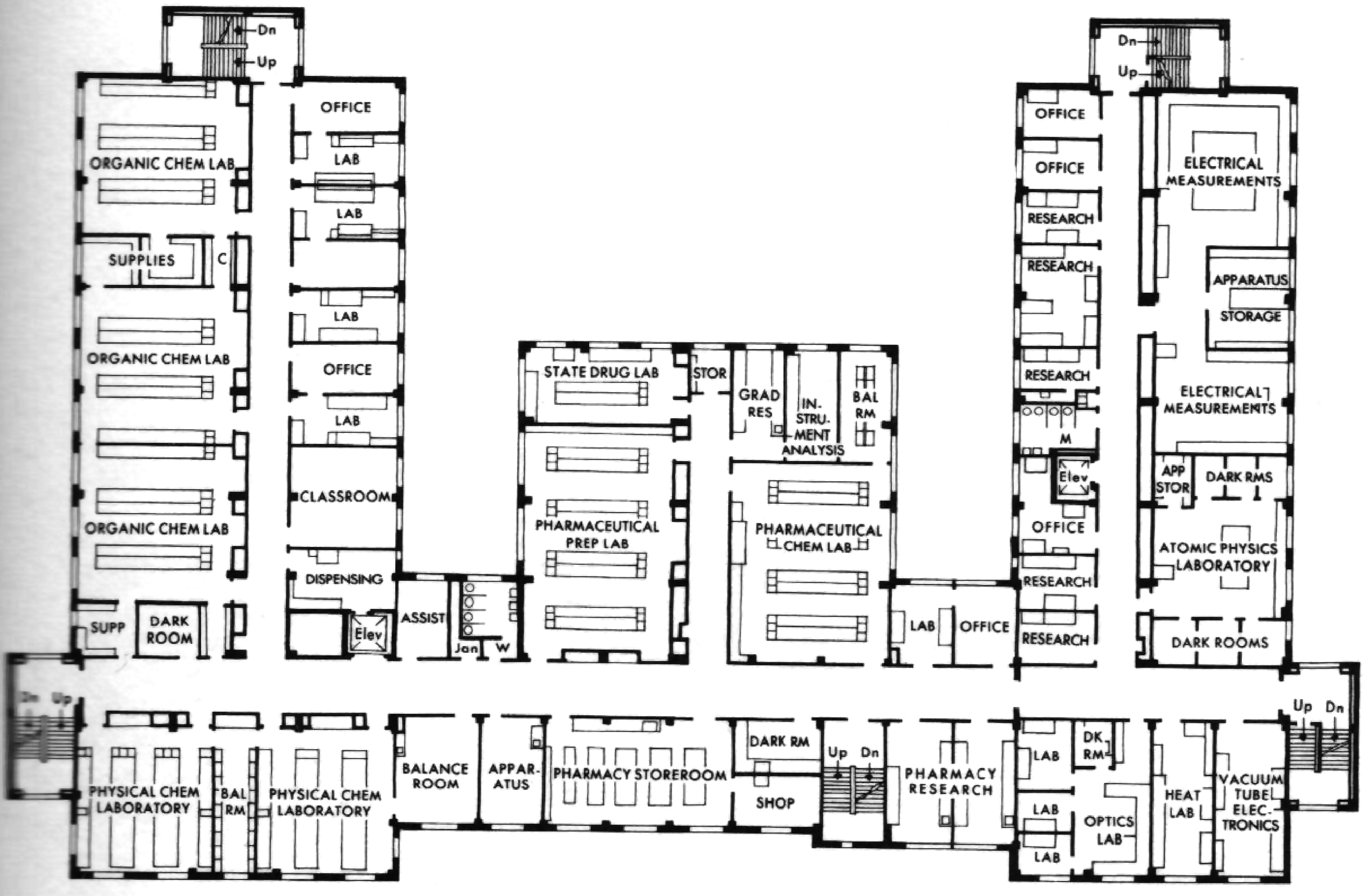
BASEMENT FLOOR PLAN


Dn
ORGANIC CHEMISTRY RESEARCH
OZONIZER
HYDRO-GEN-ATOR
LAB
OFFICE
DISTILLATION
SUPP
ORGANIC CHEMISTRY RESEARCH
ORGANIC CHEMISTRY RESEARCH
DISTILLATION
SUPP
OFFICE
LAB
ORGANIC CHEMISTRY RESEARCH
DISPENSING
Elev
ASST
Jan
M
PHARMACEUTICAL CHEM RESEARCH
REDUCT RM
DISTILL & APPARATUS
SUPP
STOR
ANIMAL ROOM
PHARMA-COLOGY RESEARCH
PHARMACOLOGY & PHARMACOGNOSY LAB
LAB
OFFICE
ROOF
Dn
Up
ORGANIC CHEMISTRY RESEARCH
ORGANIC PREP & ORGANIC QUALITATIVE
RES & SAMPLES
OFFICE
POST-DOCTOR RES
PHAR ASSIST
PREP & SPECIAL PROBLEMS
Up
Dn
TOXICOLOGY LABORATORY

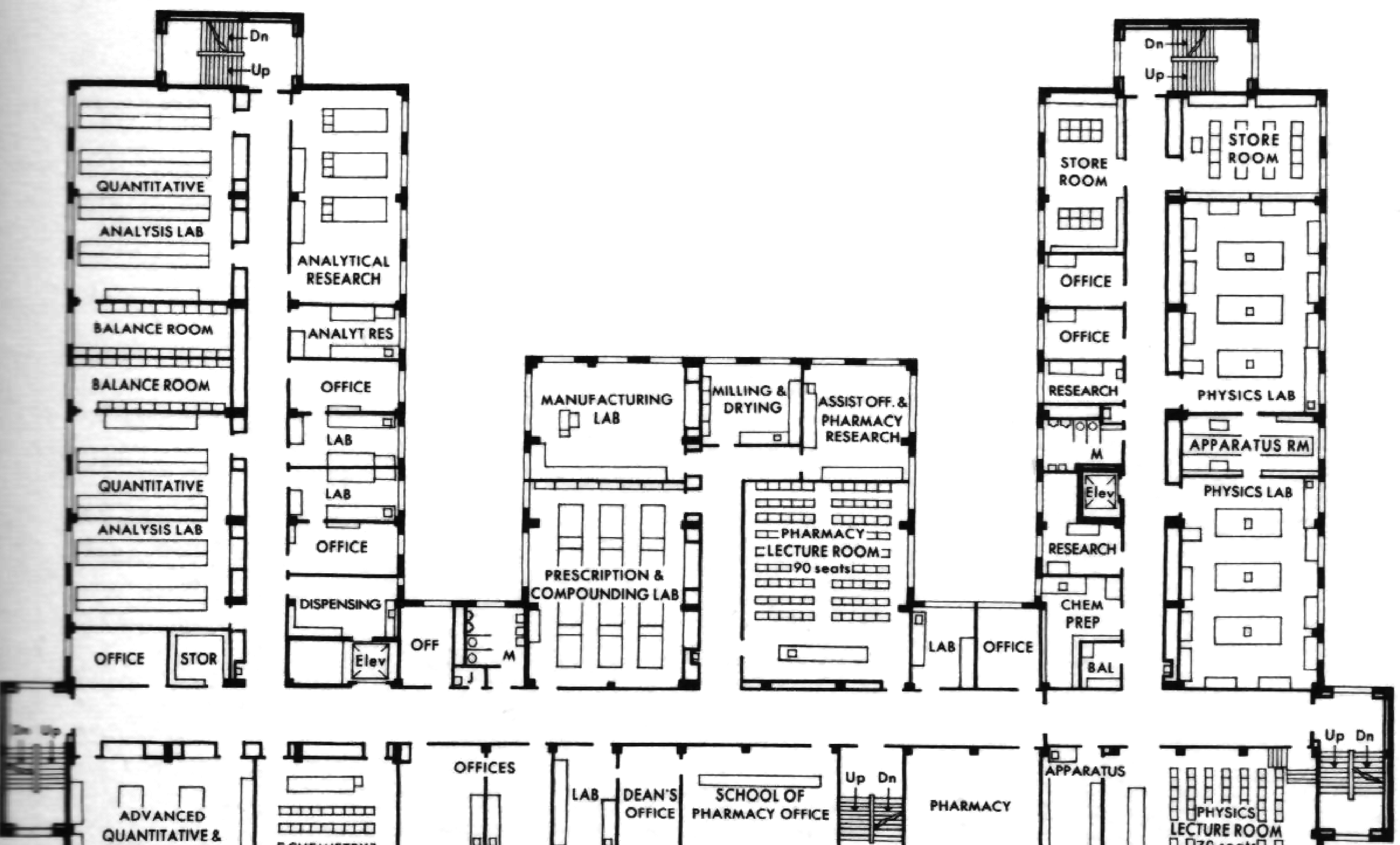
FIFTH FLOOR PLAN


ROOF
ATTIC
Up
STACK ROOM
Elev
M
J
W
Dn
READING ROOM
READING ROOM
Dn
ROOF

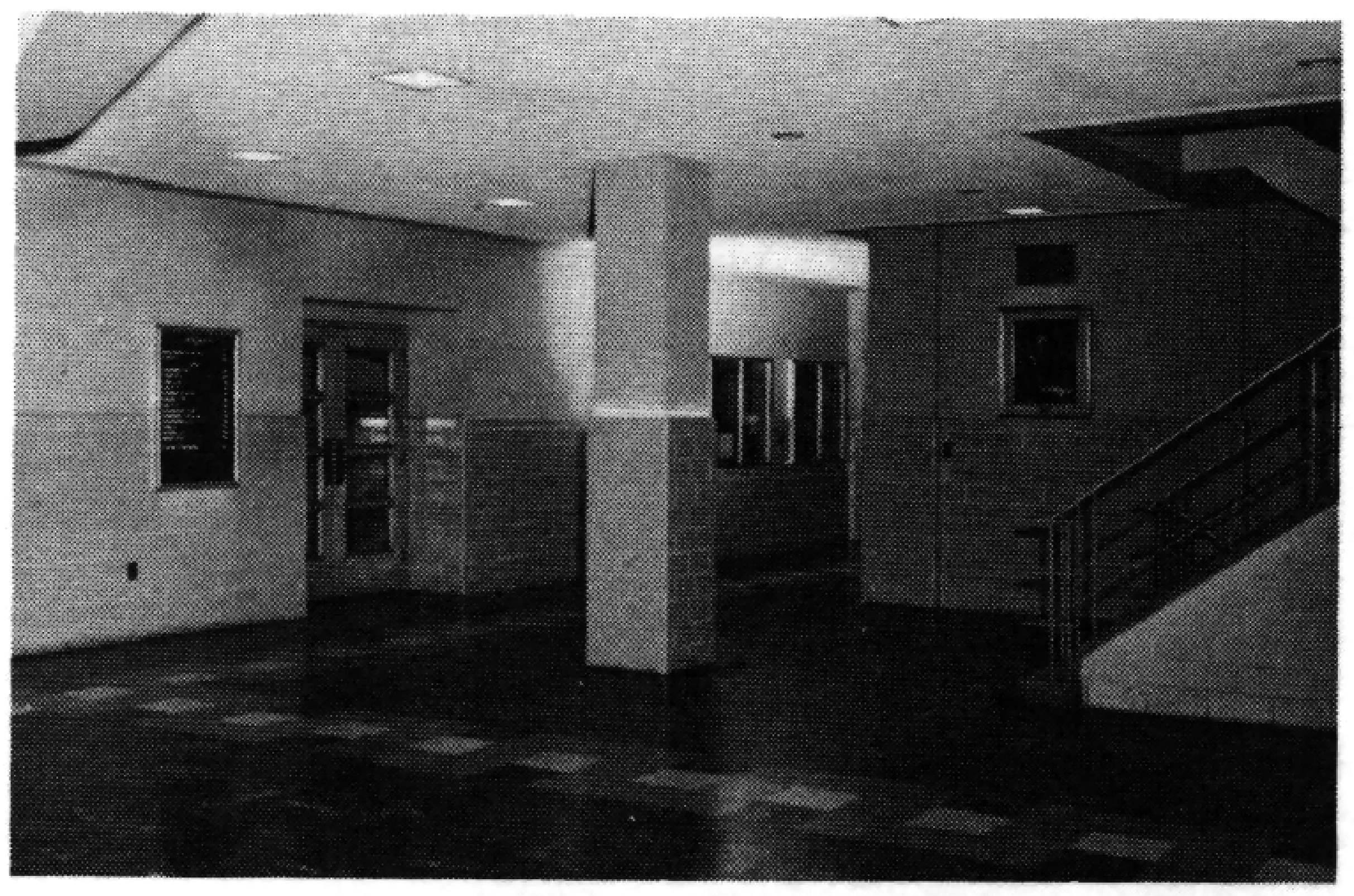
SIXTH FLOOR PLAN


Dn
Up
OFFICE
LAB
ORGANIC CHEM LAB
LAB
SUPPLIES
C
LAB
ORGANIC CHEM LAB
OFFICE
LAB
CLASSROOM
ORGANIC CHEM LAB
DISPENSING
SUPP
DARK ROOM
Elev
ASSIST
Jan
W
STATE DRUG LAB
STOR
GRAD RES
IN-STRU-MENT ANALYSIS
BAL RM
PHARMACEUTICAL PREP LAB
PHARMACEUTICAL CHEM LAB
LAB
OFFICE
Dn
Up
OFFICE
OFFICE
RESEARCH
RESEARCH
RESEARCH
M
Elev
OFFICE
RESEARCH
RESEARCH
ELECTRICAL MEASUREMENTS
APPARATUS
STORAGE
ELECTRICAL MEASUREMENTS
APP STOR
DARK RMS
ATOMIC PHYSICS LABORATORY
DARK ROOMS
Dn
Up
PHYSICAL CHEM LABORATORY
BAL RM
PHYSICAL CHEM LABORATORY
BALANCE ROOM
APPAR-ATUS
PHARMACY STOREROOM
DARK RM
SHOP
Up
Dn
PHARMACY RESEARCH
LAB
DK RM
LAB
LAB
OPTICS LAB
HEAT LAB
VACUUM TUBE ELEC-TRONICS
Up
Dn

FOURTH FLOOR PLAN

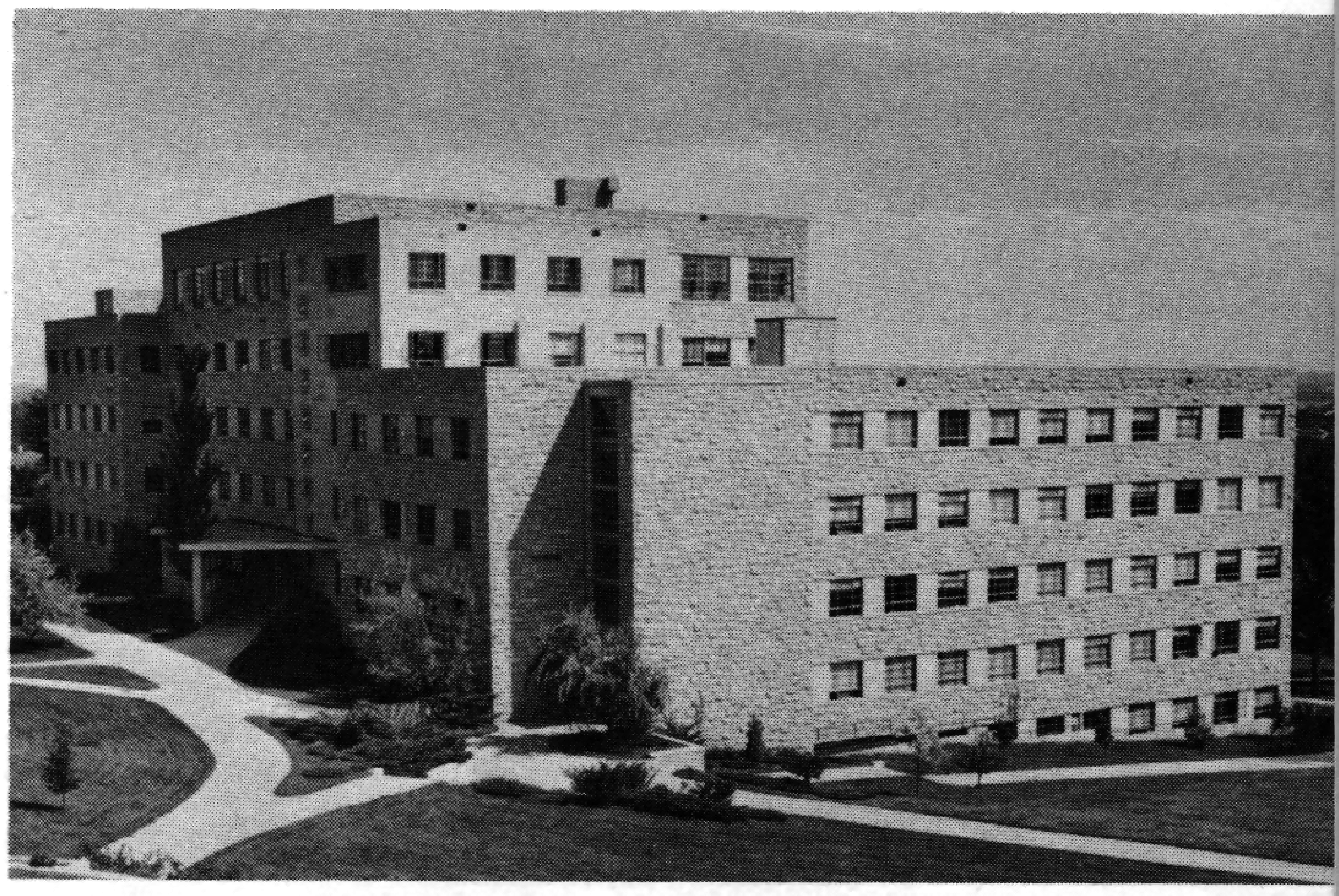

Dn
Up
QUANTITATIVE ANALYSIS LAB
ANALYTICAL RESEARCH
BALANCE ROOM
ANALYT RES
BALANCE ROOM
OFFICE
LAB
QUANTITATIVE ANALYSIS LAB
LAB
OFFICE
DISPENSING
OFFICE
STOR
Elev
OFF
J
M
MANUFACTURING LAB
MILLING & DRYING
ASSIST OFF. & PHARMACY RESEARCH
PRESCRIPTION & COMPOUNDING LAB
PHARMACY LECTURE ROOM 90 seats
LAB
OFFICE
Dn
Up
STORE ROOM
OFFICE
OFFICE
RESEARCH
Elev
RESEARCH
CHEM PREP
BAL
STORE ROOM
PHYSICS LAB
APPARATUS RM
PHYSICS LAB
Dn
Up
ADVANCED QUANTITATIVE & FOOD ANALYSIS
CHEMISTRY
OFFICES
LAB
DEAN'S OFFICE
SCHOOL OF PHARMACY OFFICE
Up
Dn
PHARMACY
APPARATUS
PHYSICS LECTURE ROOM 70 seats
Up
Dn

THIRD FLOOR PLAN



View of principal lobby looking toward Physics Department to right of entrance door.

Malott Hall from the northwest. The 5-story wing in the foreground and some rooms in the rear center section are devoted to physics. A common library for physics, chemistry and pharmacy is housed in the center section.



24.

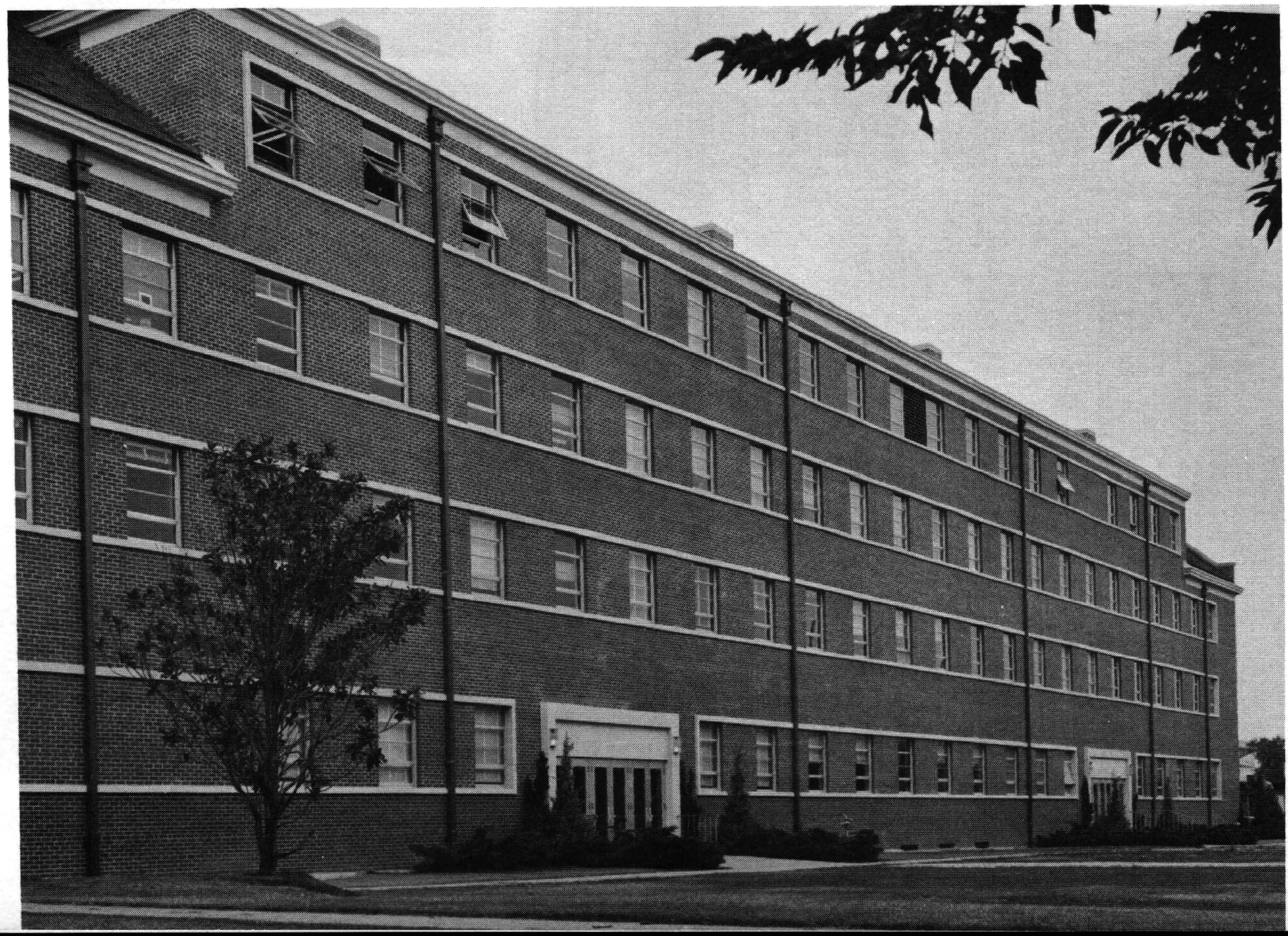
Chemistry-Physics Building
Oklahoma State University
Stillwater, Oklahoma

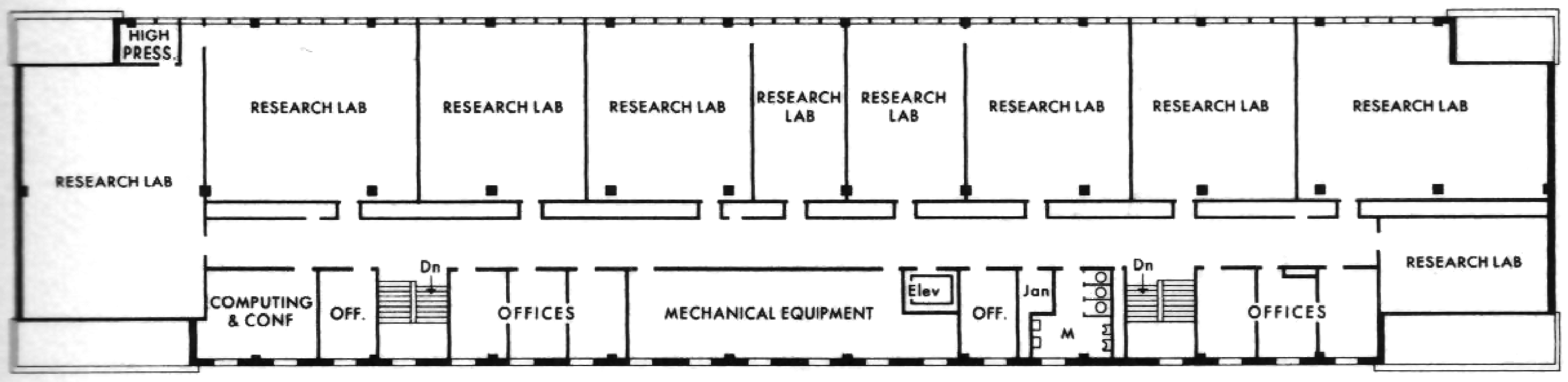
Architects:	Leon B. Senter Tulsa, Oklahoma
Associated Architects:	Phil Wilber and Associates
Completed:	June 1958
Gross Area of Building:	77,140 sq. ft.
Total Cost of Building:	$1,440,000*
Air Conditioning:	This building was planned for air conditioning and all facilities except compressors built in. The compressors will be included in the next wing to supply chilled water from a central unit.

---

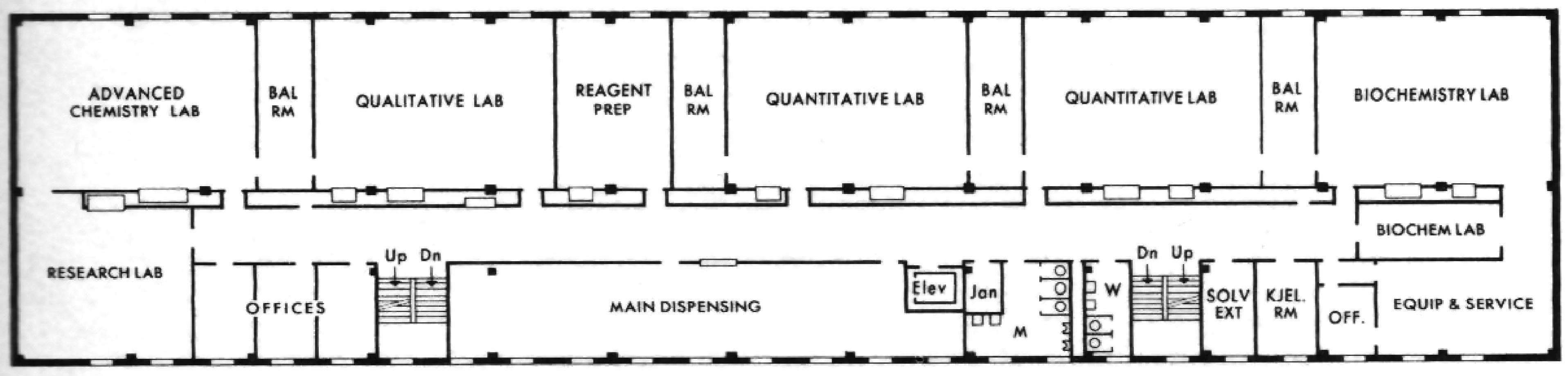
* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

Unadorned exterior of building which houses well-planned facilities.

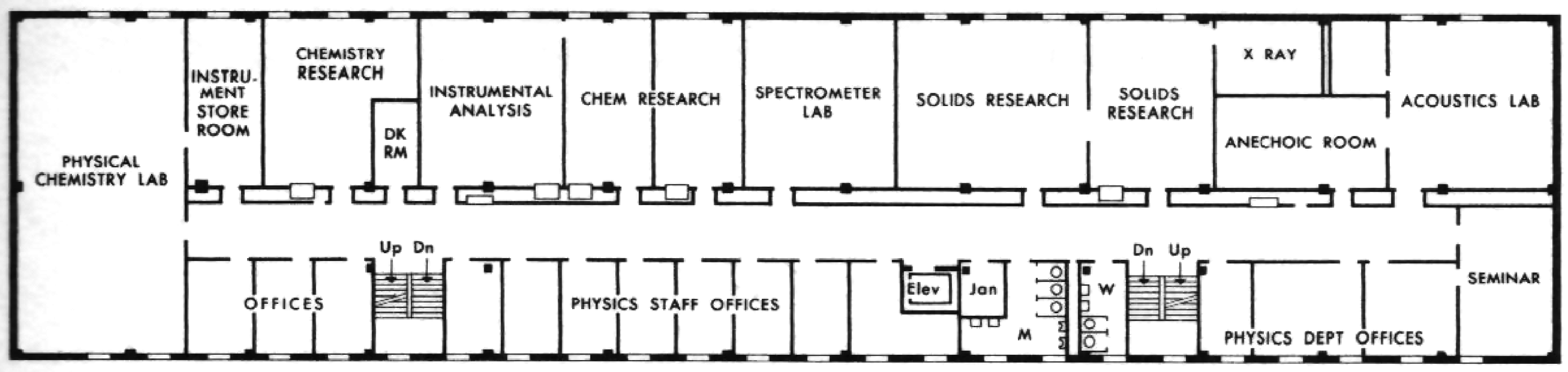



HIGH PRESS.
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
RESEARCH LAB
COMPUTING & CONF
OFF.
Dn
OFFICES
MECHANICAL EQUIPMENT
Elev
OFF.
Jan
M
Dn
OFFICES

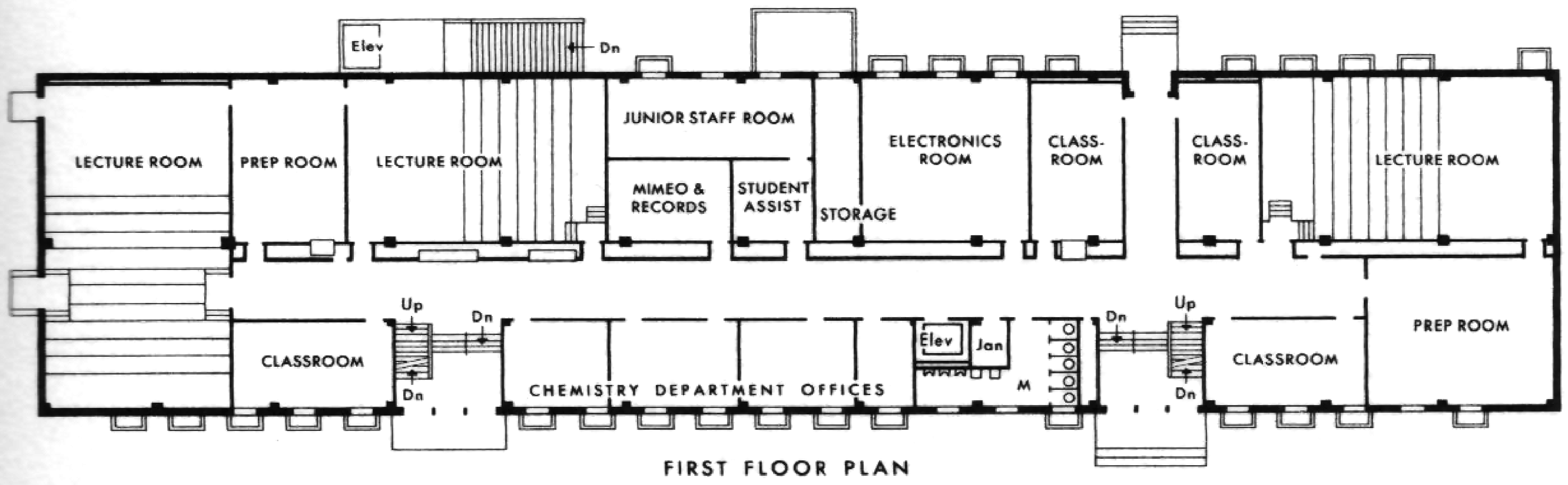
FOURTH FLOOR PLAN


ADVANCED CHEMISTRY LAB
BAL RM
QUALITATIVE LAB
REAGENT PREP
BAL RM
QUANTITATIVE LAB
BAL RM
QUANTITATIVE LAB
BAL RM
BIOCHEMISTRY LAB
BIOCHEM LAB
RESEARCH LAB
OFFICES
Up Dn
MAIN DISPENSING
Elev
Jan
M
W
Dn Up
SOLV EXT
KJEL. RM
OFF.
EQUIP & SERVICE

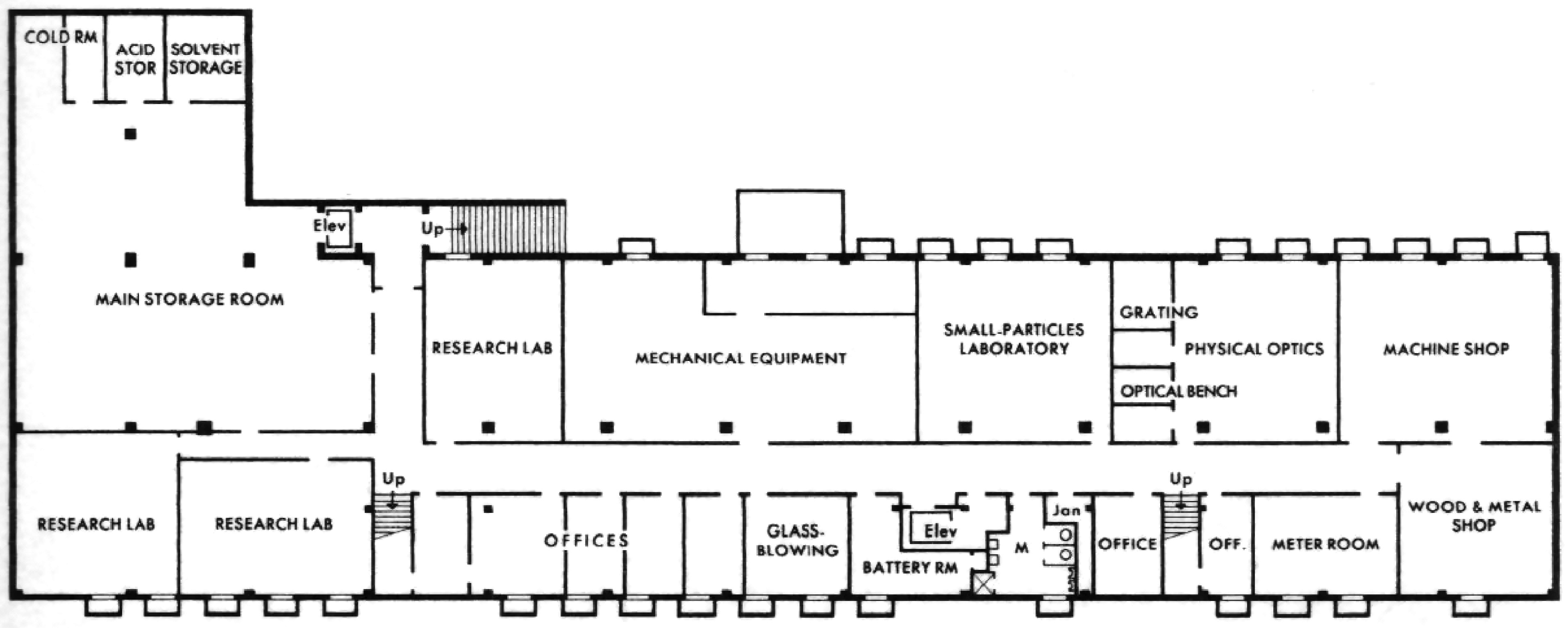
THIRD FLOOR PLAN


PHYSICAL CHEMISTRY LAB
INSTRUMENT STORE ROOM
CHEMISTRY RESEARCH
DK RM
INSTRUMENTAL ANALYSIS
CHEM RESEARCH
SPECTROMETER LAB
SOLIDS RESEARCH
SOLIDS RESEARCH
X RAY
ANECHOIC ROOM
ACOUSTICS LAB
OFFICES
Up Dn
PHYSICS STAFF OFFICES
Elev
Jan
W
Dn Up
PHYSICS DEPT OFFICES
SEMINAR

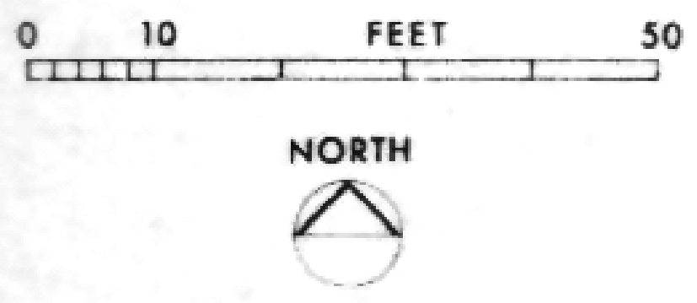
SECOND FLOOR PLAN


Elev
Dn
LECTURE ROOM
PREP ROOM
LECTURE ROOM
JUNIOR STAFF ROOM
MIMEO & RECORDS
STUDENT ASSIST
STORAGE
ELECTRONICS ROOM
CLASS-ROOM
CLASS-ROOM
LECTURE ROOM
CLASSROOM
Up
Dn
Dn
CHEMISTRY DEPARTMENT OFFICES
Elev
Jan
M
Dn
Up
Dn
CLASSROOM
PREP ROOM

FIRST FLOOR PLAN


COLD RM
ACID STOR
SOLVENT STORAGE
Elev
Up
MAIN STORAGE ROOM
RESEARCH LAB
MECHANICAL EQUIPMENT
SMALL-PARTICLES LABORATORY
GRATING
PHYSICAL OPTICS
OPTICAL BENCH
MACHINE SHOP
RESEARCH LAB
RESEARCH LAB
Up
OFFICES
GLASS-BLOWING
Elev
BATTERY RM
M
Jan
OFFICE
Up
OFF.
METER ROOM
WOOD & METAL SHOP

BASEMENT FLOOR PLAN


0
10
FEET
50
NORTH

Close-up of entrance doors.

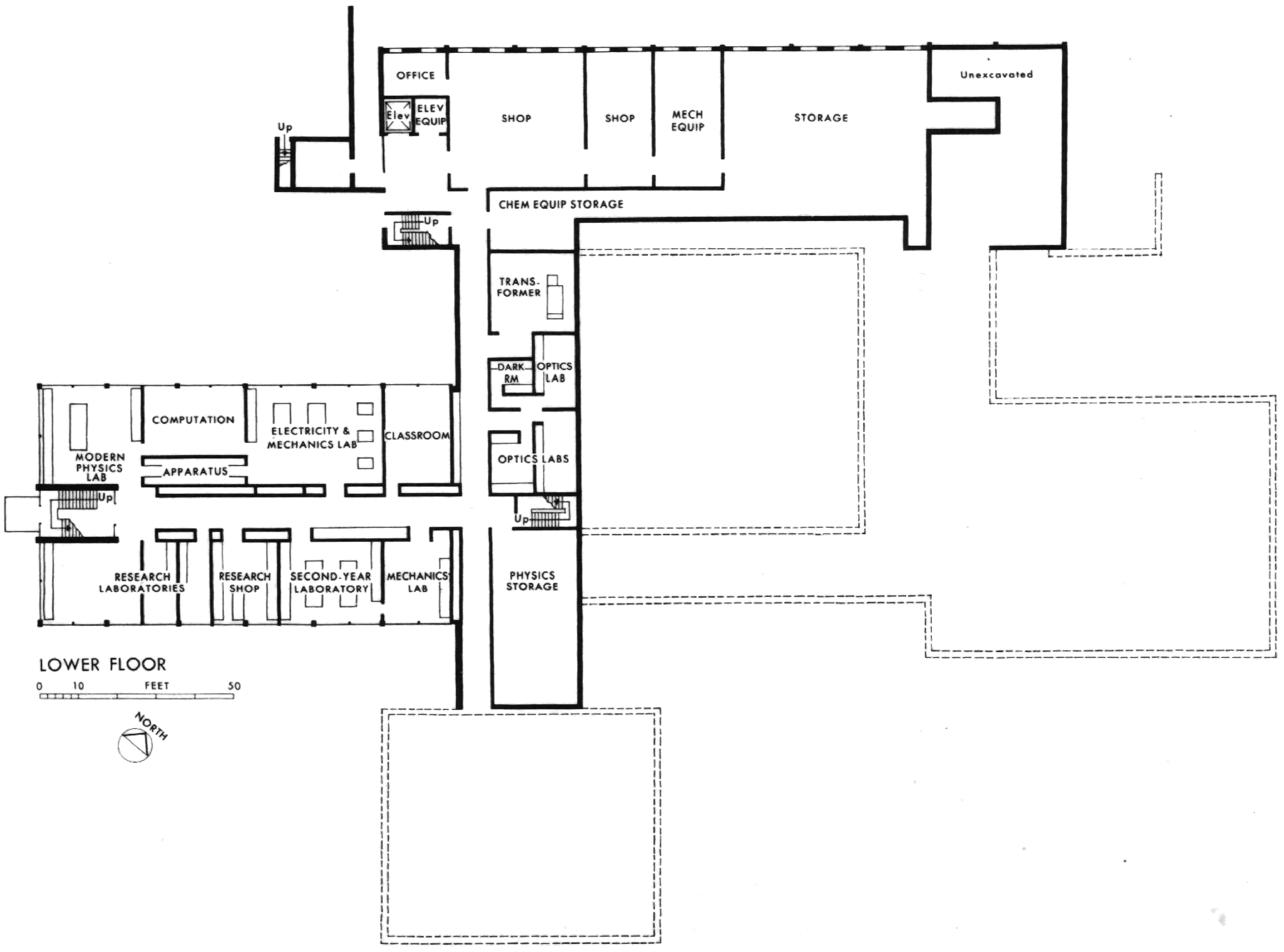
25.

Pierre S. duPont Science Building
Swarthmore College
Swarthmore, Pennsylvania

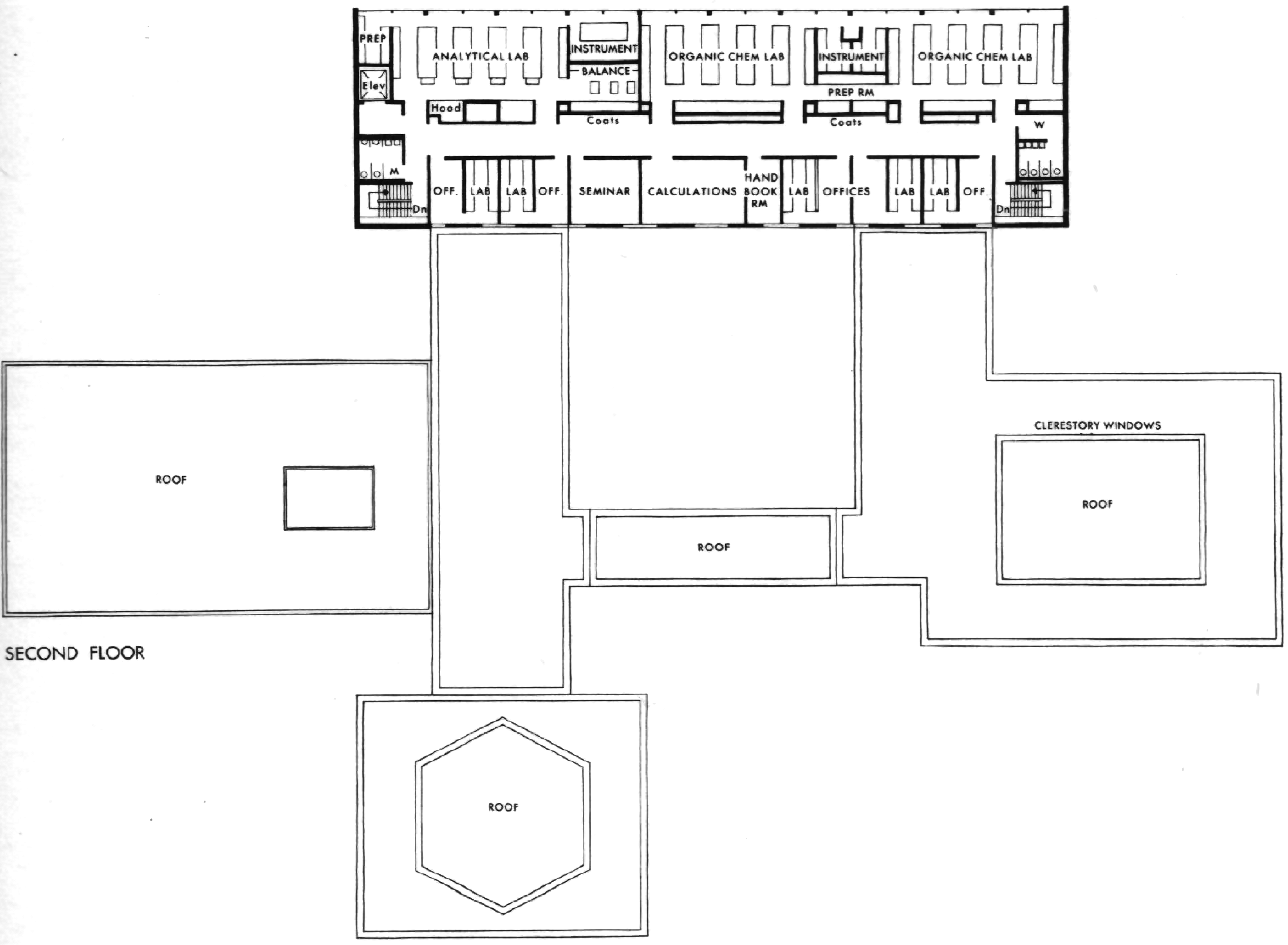
Architects:	Vincent G. Kling Philadelphia, Pennsylvania
Completed:	September 1960
Gross Area of Building:	70,663 sq. ft.*
Total Cost of Building:	$1,800,000**
Air Conditioning:	None

* Gross, includes porches and covered walkway.
** Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

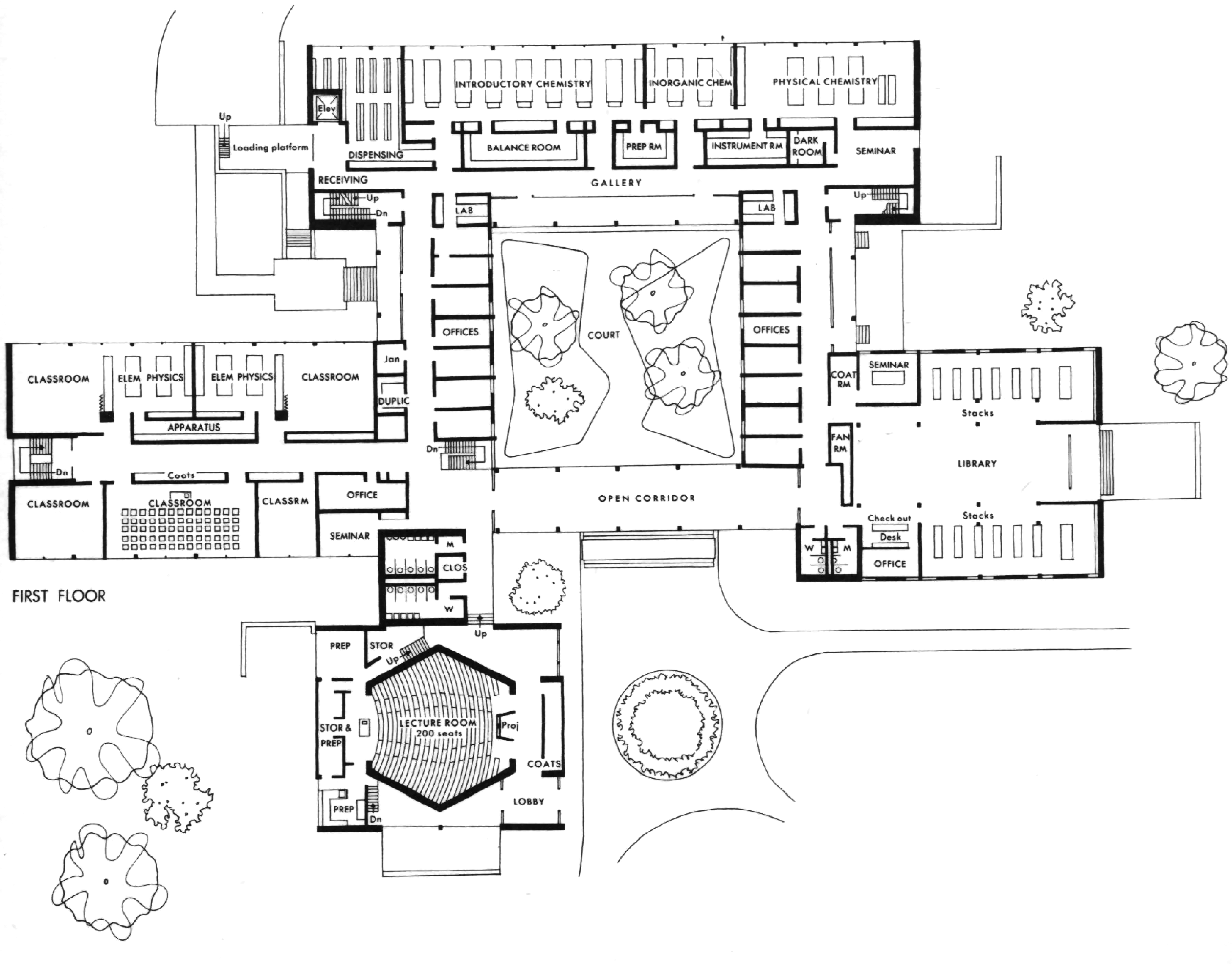
View from an adjoining building. Physics is located principally in the two-story wing at left. The center polygonal form with porches contains the lecture room; the library is at far right. Wall panels are precast concrete with exposed aggregates on a concrete frame.


OFFICE
Elev
ELEV EQUIP
SHOP
SHOP
MECH EQUIP
STORAGE
Unexcavated
Up
CHEM EQUIP STORAGE
Up
TRANS-FORMER
DARK RM
OPTICS LAB
OPTICS LABS
Up
PHYSICS STORAGE
COMPUTATION
ELECTRICITY & MECHANICS LAB
CLASSROOM
MODERN PHYSICS LAB
APPARATUS
Up
RESEARCH LABORATORIES
RESEARCH SHOP
SECOND-YEAR LABORATORY
MECHANICS LAB
0 10 FEET 50
NORTH

LOWER FLOOR


PREP
Elev
ANALYTICAL LAB
INSTRUMENT
BALANCE
Hood
Coats
ORGANIC CHEM LAB
INSTRUMENT
PREP RM
Coats
ORGANIC CHEM LAB
W
M
OFF.
LAB
LAB
OFF.
SEMINAR
CALCULATIONS
HAND BOOK RM
LAB
OFFICES
LAB
LAB
OFF.
Dn
Dn
ROOF
ROOF
CLERESTORY WINDOWS
ROOF
ROOF

SECOND FLOOR

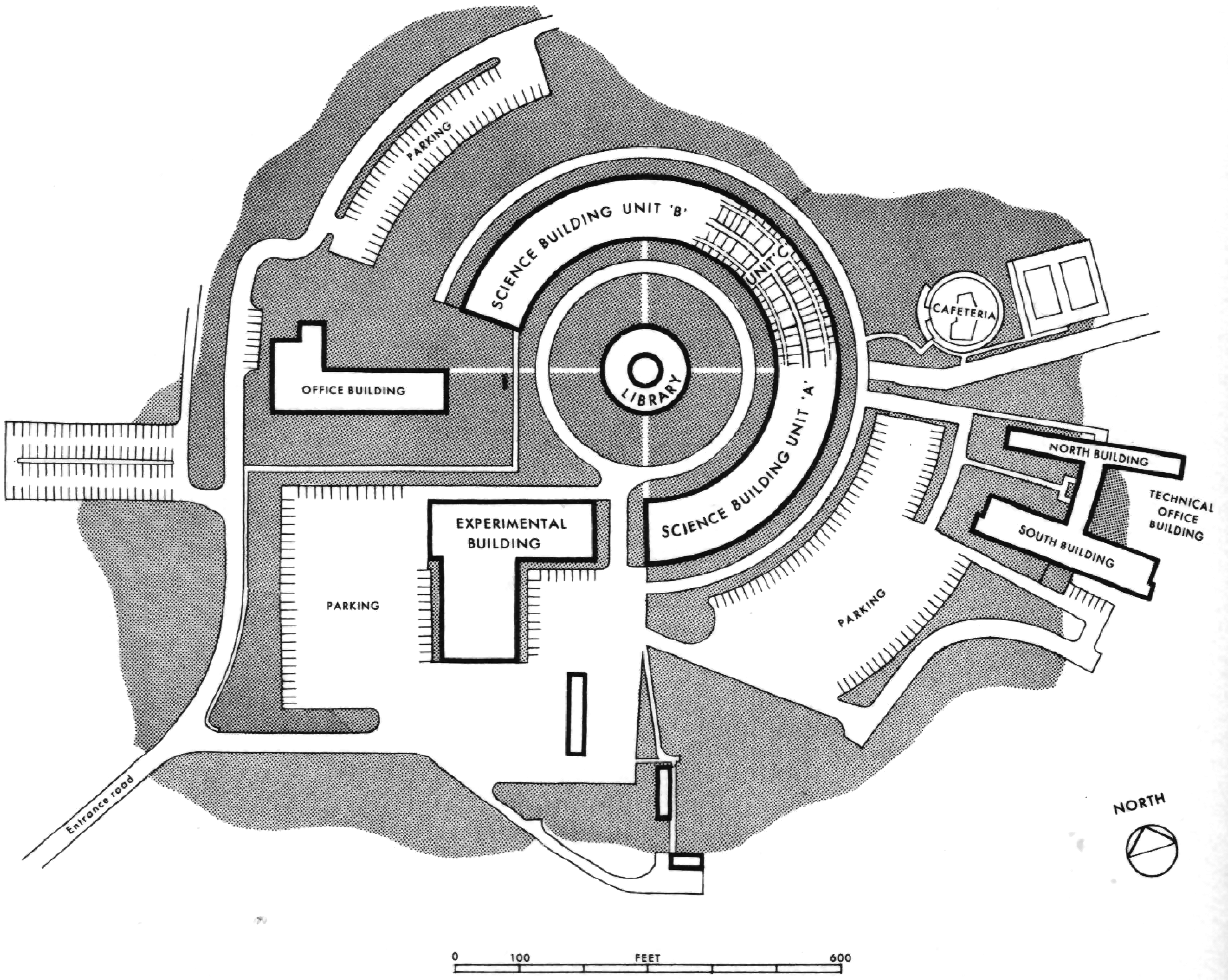

Up
Loading platform
Elev
DISPENSING
RECEIVING
Up
Dn
INTRODUCTORY CHEMISTRY
BALANCE ROOM
INORGANIC CHEM
PREP RM
PHYSICAL CHEMISTRY
INSTRUMENT RM
DARK ROOM
SEMINAR
GALLERY
LAB
LAB
Up
OFFICES
COURT
OFFICES
COAT RM
SEMINAR
Stacks
FAN RM
LIBRARY
Stacks
Check out
Desk
W
M
OFFICE
CLASSROOM
ELEM PHYSICS
ELEM PHYSICS
CLASSROOM
Jan
DUPLIC
APPARATUS
Dn
Dn
Coats
CLASSROOM
CLASSROOM
CLASSRM
OFFICE
SEMINAR
OPEN CORRIDOR
M
CLOS
W
Up
PREP
STOR
Up
STOR & PREP
LECTURE ROOM
200 seats
Proj
COATS
LOBBY
PREP
Dn

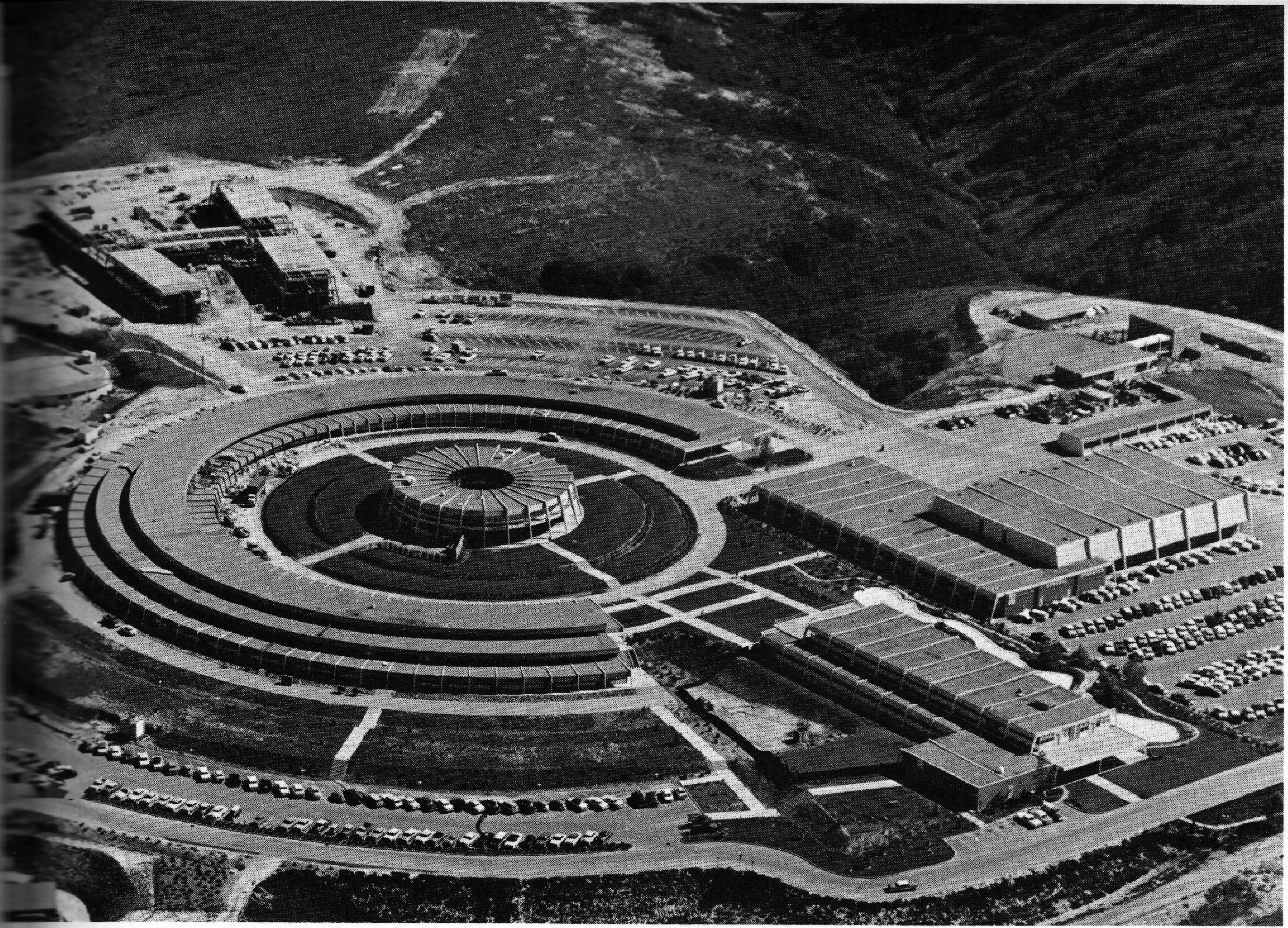
FIRST FLOOR

26.

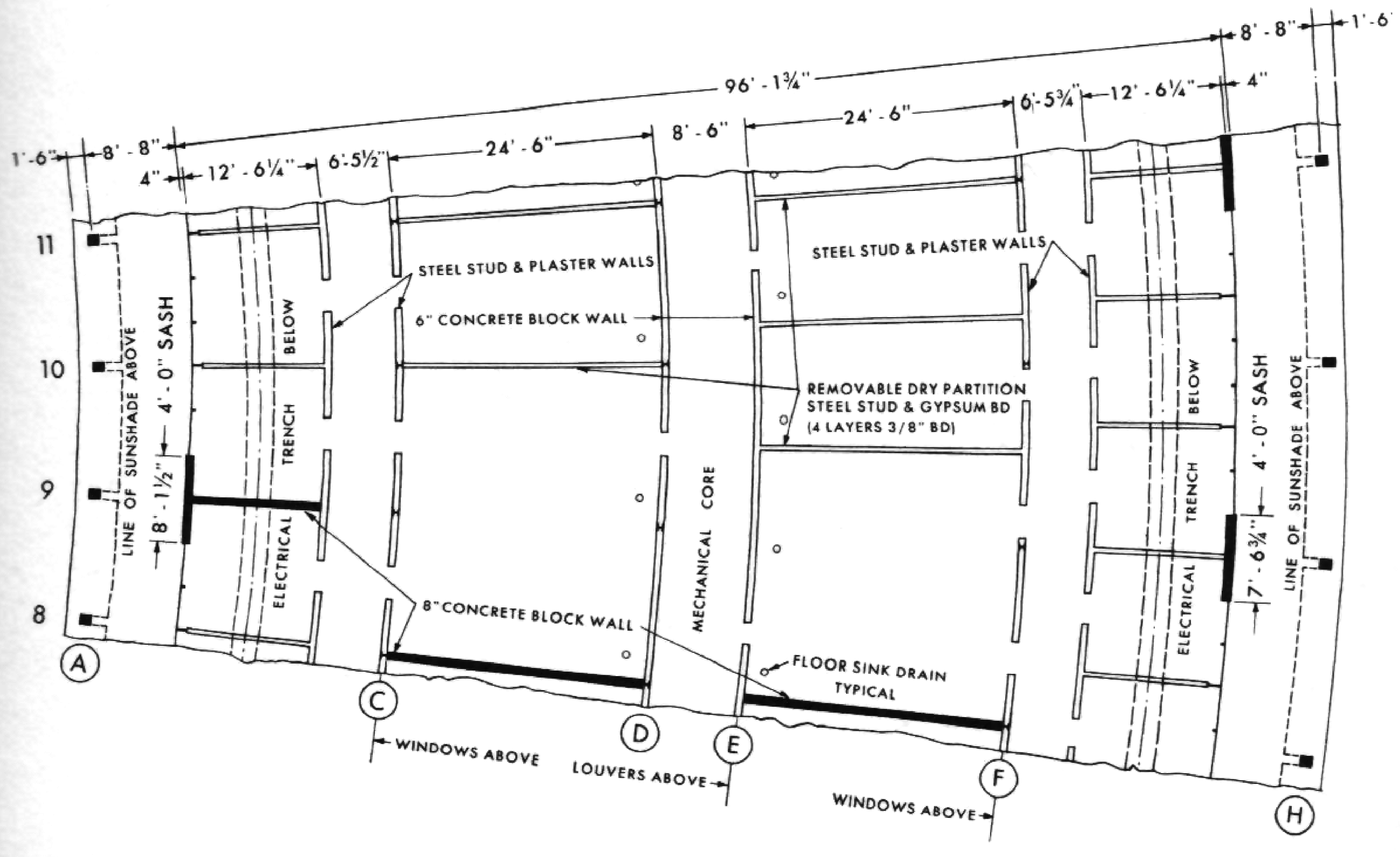
Laboratory Building
John Jay Hopkins Laboratory
General Atomic
San Diego, California

Architects:	Perriera & Luckman Los Angeles, California
Completed:	June 1960
Gross Area of Building:	138,275 sq. ft.
Total Cost of Building:	Not available
Air Conditioning:	700 ton reheat system. There are two central plants that distribute chilled water to coils in three mechanical rooms which in turn distribute forced air to labs and offices. Laboratories have their own thermostat and supply duct with a reheat coil to temper air. Each laboratory has individual exhaust system. All office areas are a zoned system with recirculated air.


PARKING
SCIENCE BUILDING UNIT 'B'
UNIT 'C'
CAFETERIA
OFFICE BUILDING
LIBRARY
SCIENCE BUILDING UNIT 'A'
NORTH BUILDING
TECHNICAL OFFICE BUILDING
SOUTH BUILDING
EXPERIMENTAL BUILDING
PARKING
PARKING
Entrance road
NORTH
0
100
FEET
600

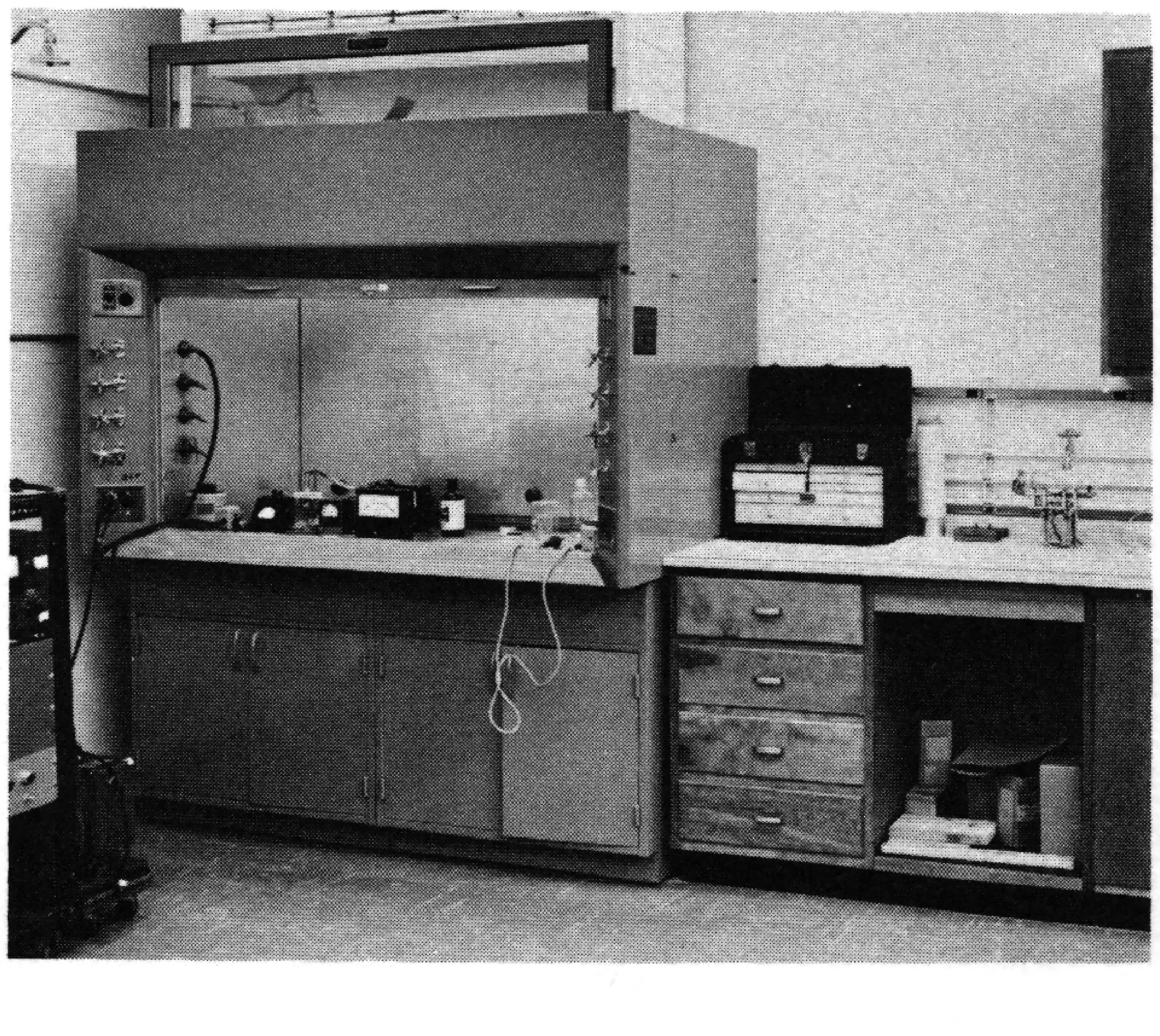


Aerial view of laboratory.


96' - 1¾"
8' - 8"
1' - 6
1' - 6"
8' - 8"
4"
12' - 6¼"
6'- 5½"
24' - 6"
8' - 6"
24' - 6"
6'- 5¾"
12' - 6¼"
4"
11
10
9
8
LINE OF SUNSHADE ABOVE
4' - 0" SASH
8' - 1½"
ELECTRICAL TRENCH BELOW
STEEL STUD & PLASTER WALLS
6" CONCRETE BLOCK WALL
REMOVABLE DRY PARTITION
STEEL STUD & GYPSUM BD
(4 LAYERS 3/8" BD)
STEEL STUD & PLASTER WALLS
MECHANICAL CORE
8" CONCRETE BLOCK WALL
FLOOR SINK DRAIN
TYPICAL
ELECTRICAL TRENCH BELOW
4' - 0" SASH
7' - 6¾"
LINE OF SUNSHADE ABOVE
A
C
D
E
F
H
WINDOWS ABOVE
LOUVERS ABOVE
WINDOWS ABOVE

TYPICAL SEGMENT OF PLAN UNIT 'C'

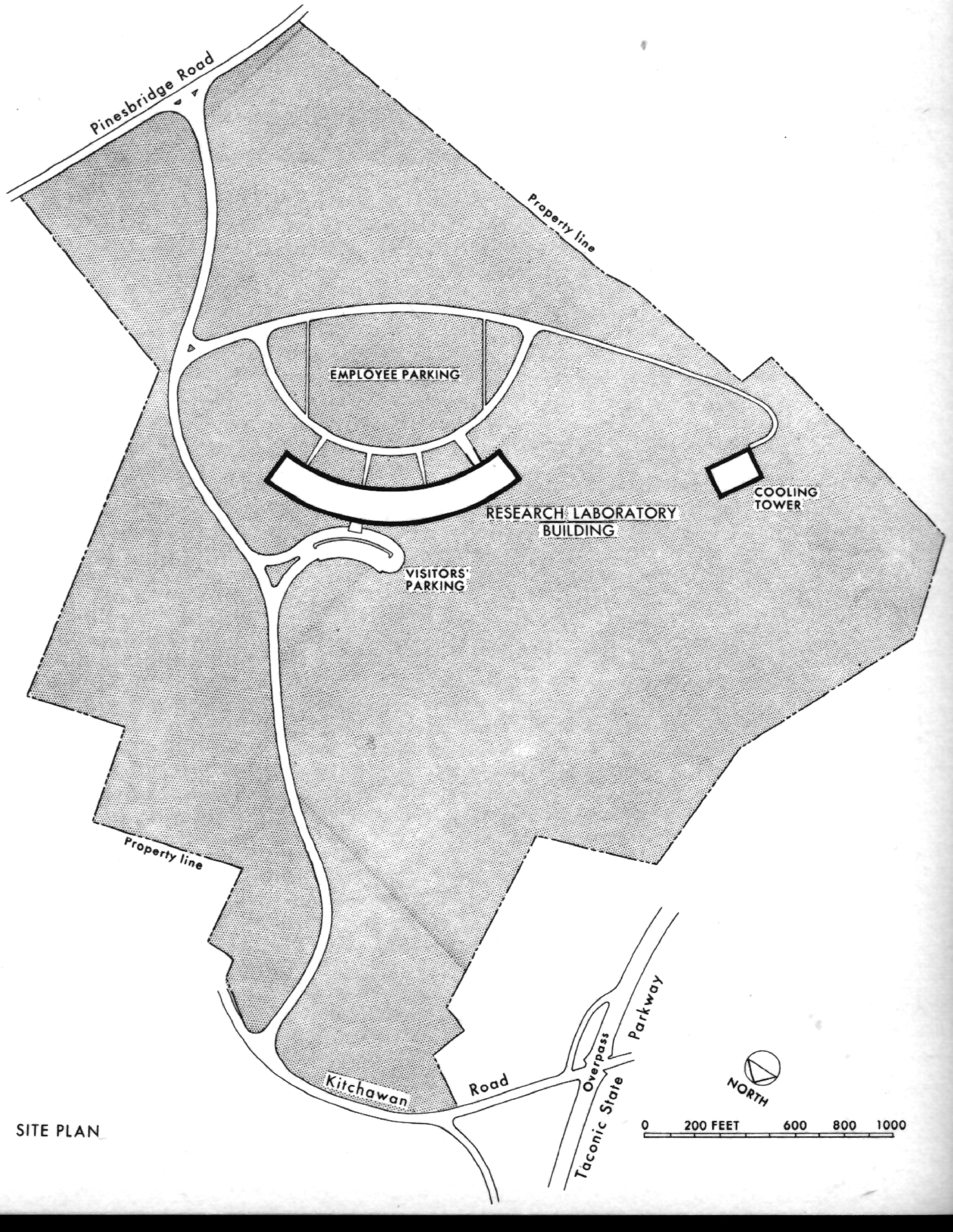
Typical research room showing laboratory furniture and fume hood in units. Services run exposed on Unistrut supports. This method for installing both furniture and services is standard with industrial and educational laboratories.



27.

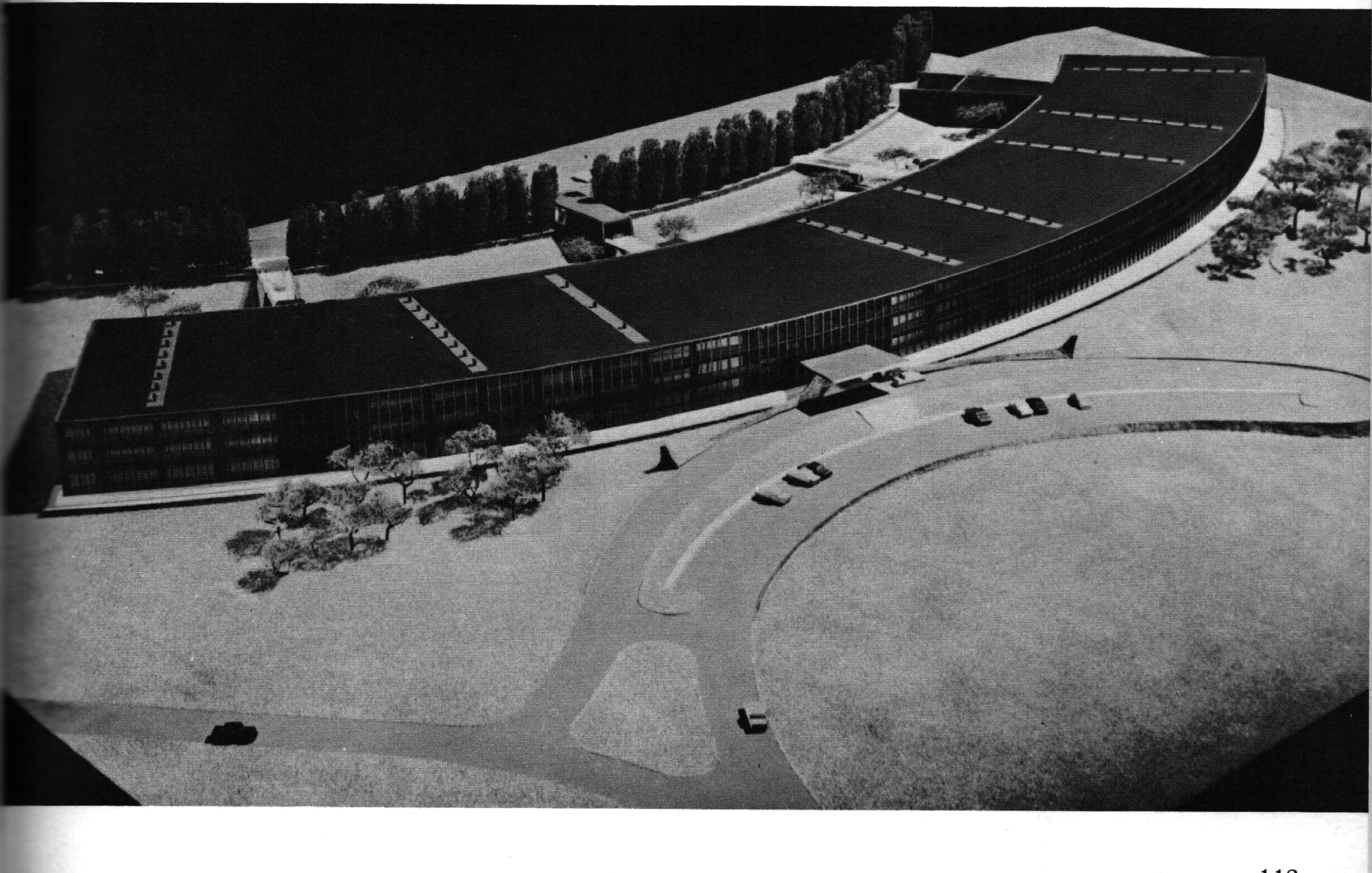
I.B.M. Research Center
Yorktown, New York

Architects:	Eero Saarinen & Associates Birmingham, Michigan
Completed:	(Scheduled) March 1961
Gross Area of Building:	459,000 sq. ft.
Total Cost of Building:	Not available
Air Conditioning:	A) Laboratory Areas—High pressure dual duct system with individual thermostat in each laboratory. Air supply at rate of 2 cu. ft. per minute per sq. ft. of laboratory space. B) Office Areas—Standard low pressure single duct system controlled by zone thermostats and humidistats. Air supplied at rate of 1 cu. ft. per minute per sq. ft. of office space. C) General Areas—Standard low pressure duct work with separate thermostats and humidistats controlling each such space. D) Special Laboratories—Where low humidity and special temperature conditions are required, these laboratories will be separately conditioned using a separate low temperature brine chiller with individual temperature and humidity controls. E) Corridors—Where exposed to solar heat additional air conditioning units are installed in corridor ceilings.

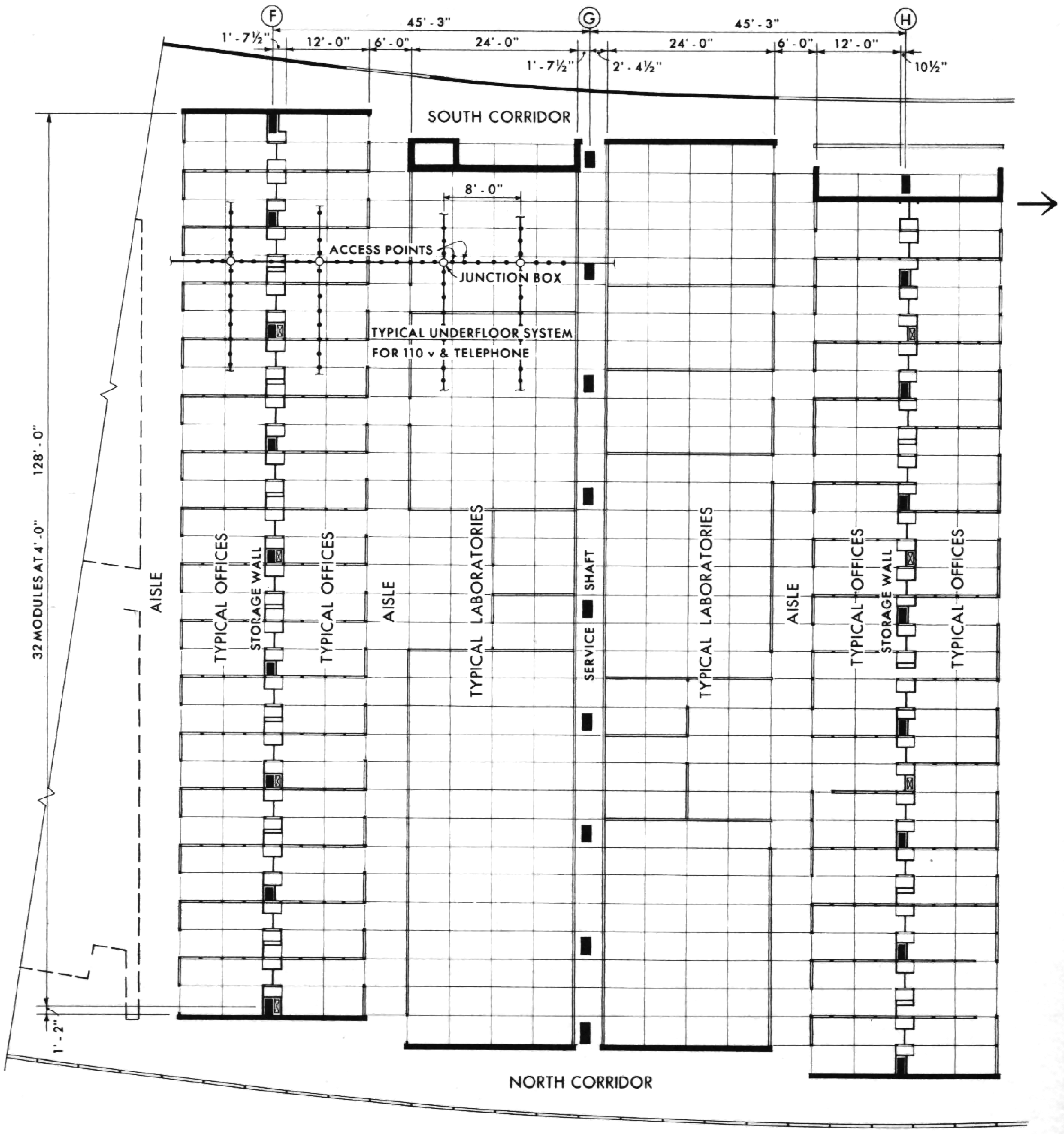

Pinesbridge Road
Property line
EMPLOYEE PARKING
RESEARCH LABORATORY BUILDING
COOLING TOWER
VISITORS' PARKING
Property line
Kitchawan Road
Overpass
Taconic State Parkway
NORTH
0 200 FEET 600 800 1000

SITE PLAN

Model of the building. The structure is curved to fit the terrain of the site and to temper the immensity of the project. The arc of approximately 74 degrees is 1,091 feet long on the front and 146 feet wide. The frame is reinforced concrete with exterior of glass and rough native stone. The same stone is used for two sides of the exterior corridor walls. (See following pages for additional plans and photograph.)

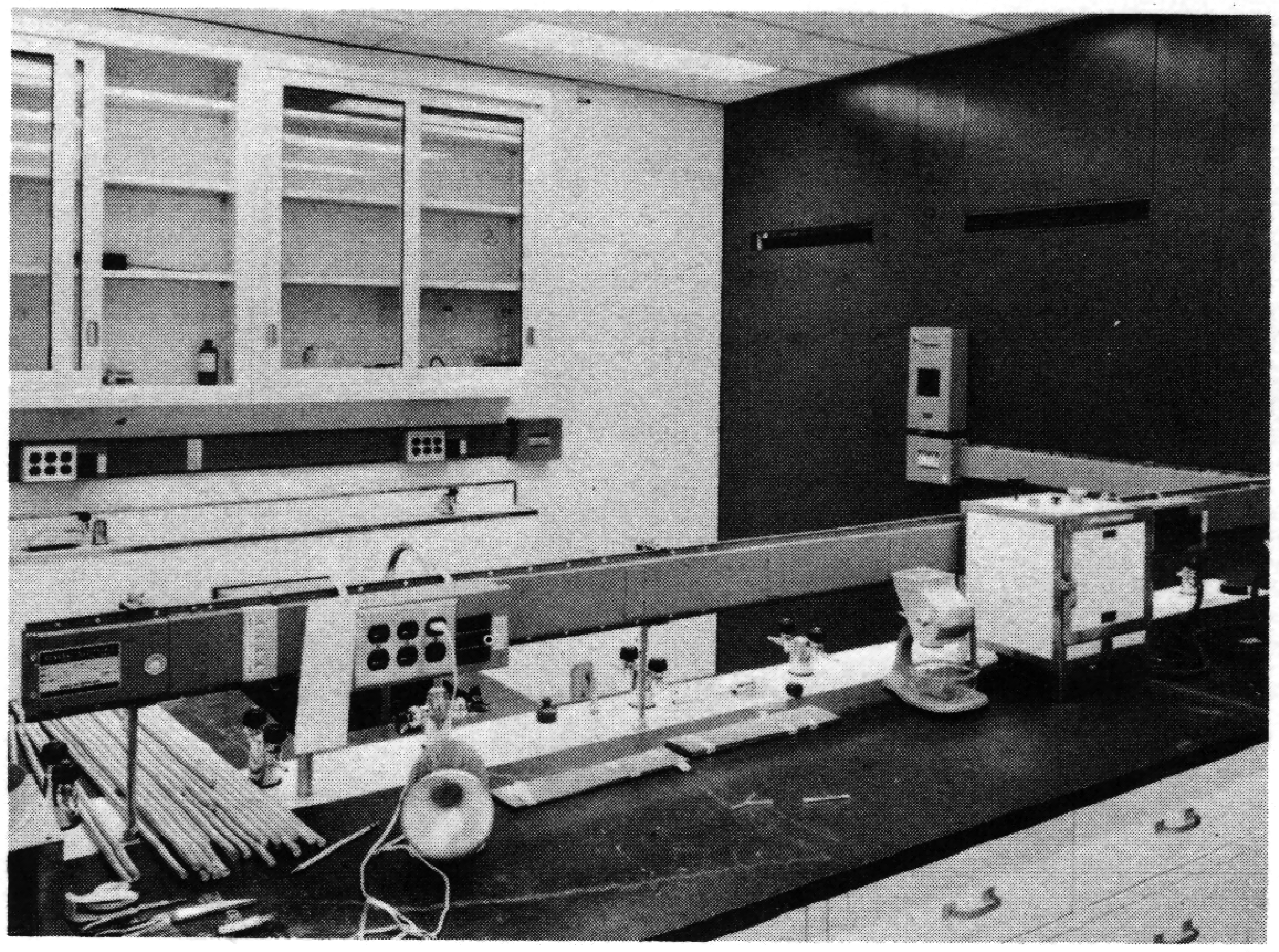


27. (Continued)
I.B.M. Research Center

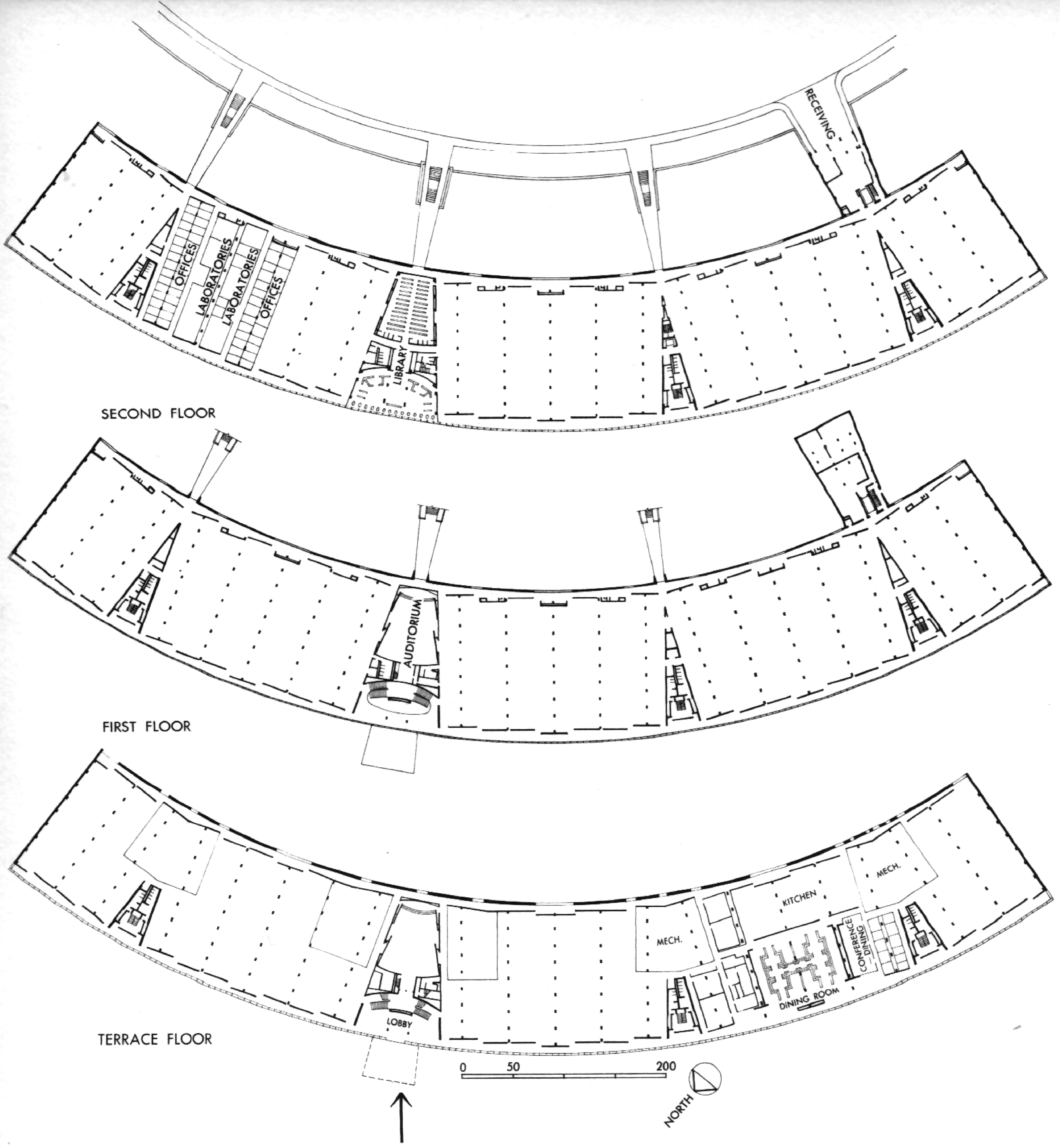


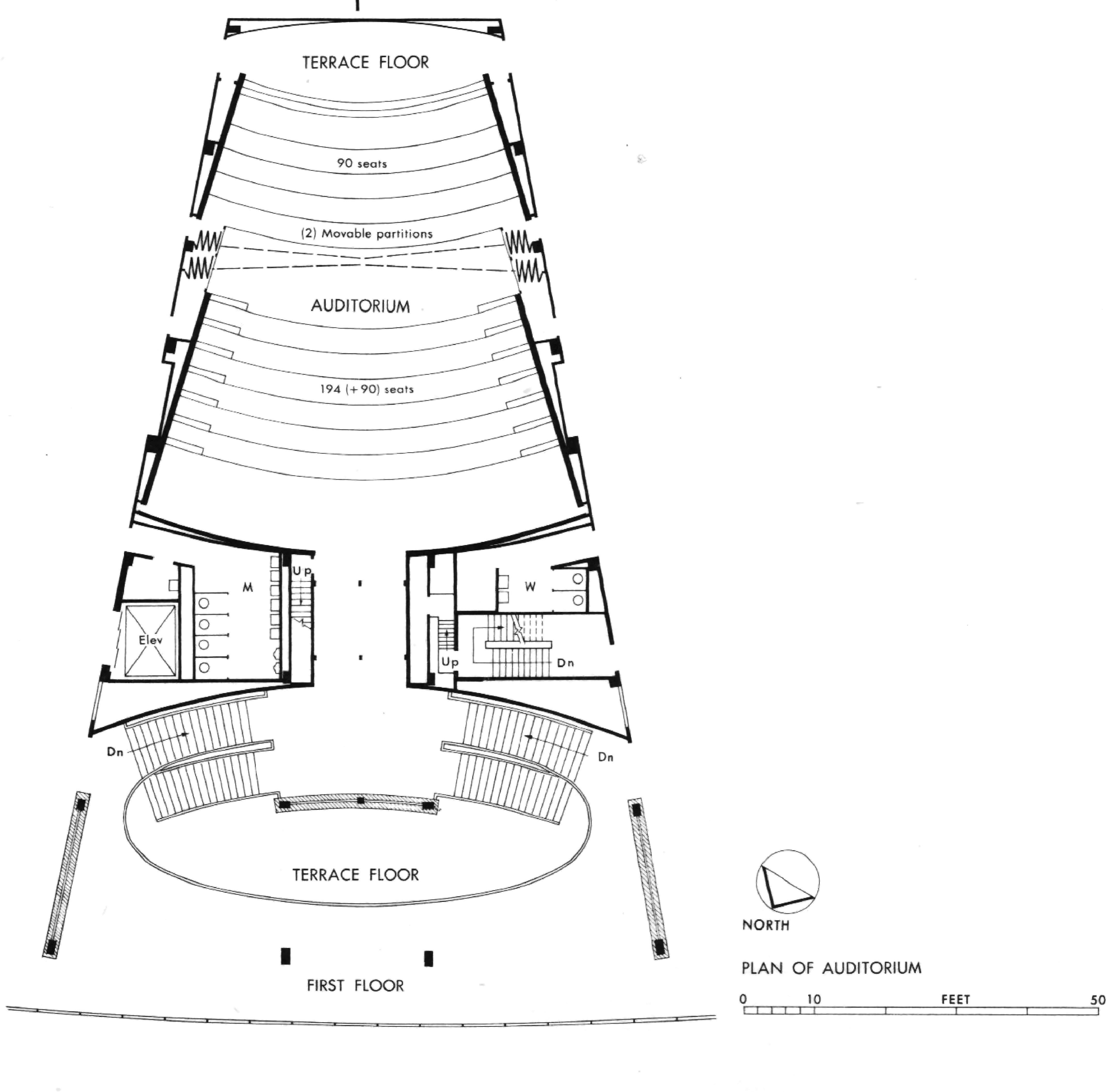
F
G
H
45' - 3"
45' - 3"
1' - 7½"
12' - 0"
6' - 0"
24' - 0"
1' - 7½"
2' - 4½"
24' - 0"
6' - 0"
12' - 0"
10½"
SOUTH CORRIDOR
8' - 0"
ACCESS POINTS
JUNCTION BOX
TYPICAL UNDERFLOOR SYSTEM FOR 110 v & TELEPHONE
128' - 0"
32 MODULES AT 4' - 0"
AISLE
TYPICAL OFFICES
STORAGE WALL
TYPICAL OFFICES
AISLE
TYPICAL LABORATORIES
SERVICE SHAFT
TYPICAL LABORATORIES
AISLE
TYPICAL OFFICES
STORAGE WALL
TYPICAL OFFICES
1' - 2"
NORTH CORRIDOR

TYPICAL SEGMENT OF PLAN



Typical laboratory showing service strips on perimeter wall and in center island. Note electrical bus duct leading to service core on rear partition at right.


RECEIVING
OFFICES
LABORATORIES
LABORATORIES
OFFICES
LIBRARY
SECOND FLOOR
AUDITORIUM
FIRST FLOOR
MECH.
KITCHEN
MECH.
CONFERENCE DINING
DINING ROOM
LOBBY
TERRACE FLOOR
0 50 200
NORTH


TERRACE FLOOR
90 seats
(2) Movable partitions
AUDITORIUM
194 (+90) seats
M
Up
Elev
W
Up
Dn
Dn
Dn
TERRACE FLOOR
FIRST FLOOR
NORTH
0 10 FEET 50

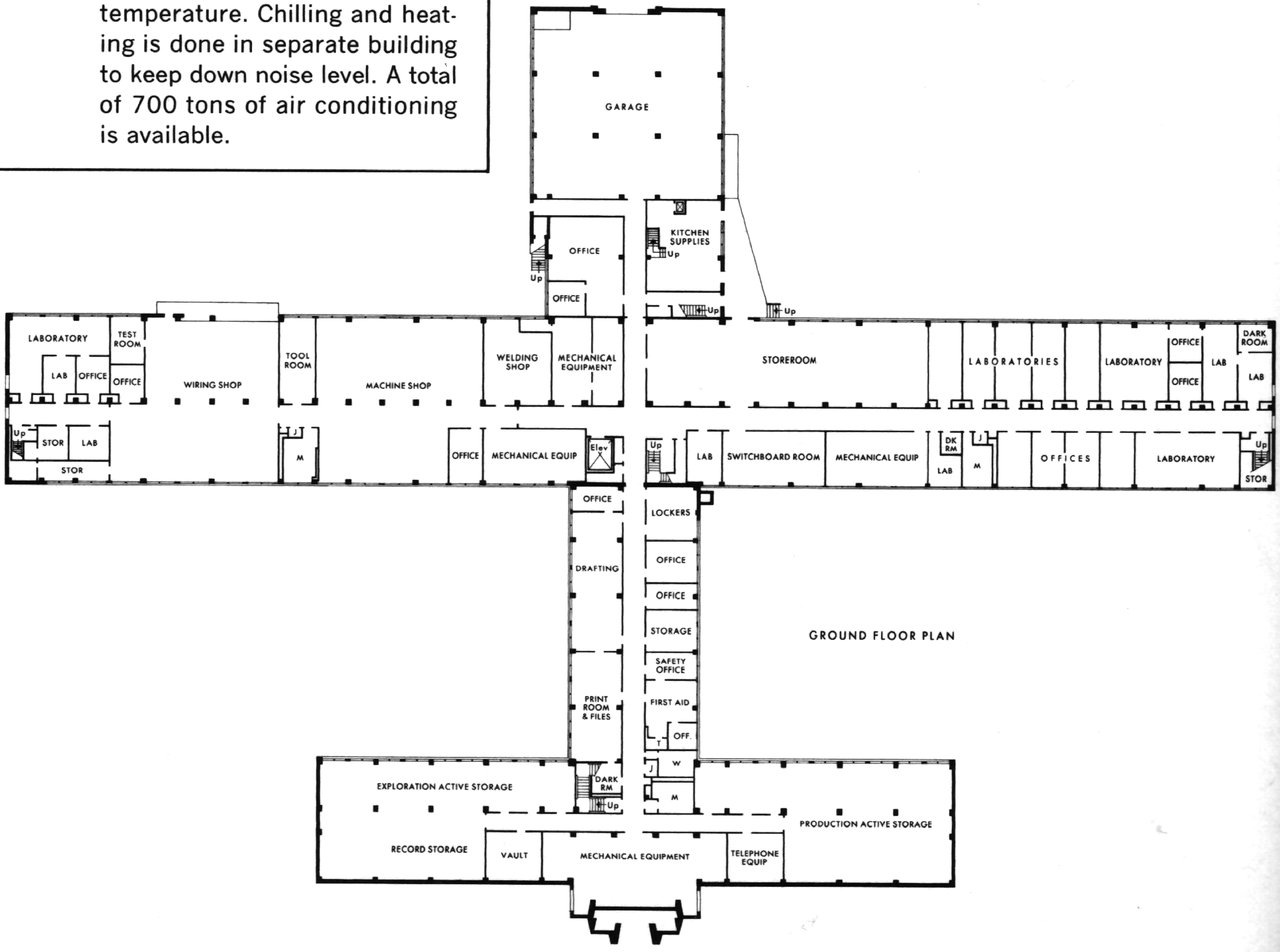
PLAN OF AUDITORIUM

28.

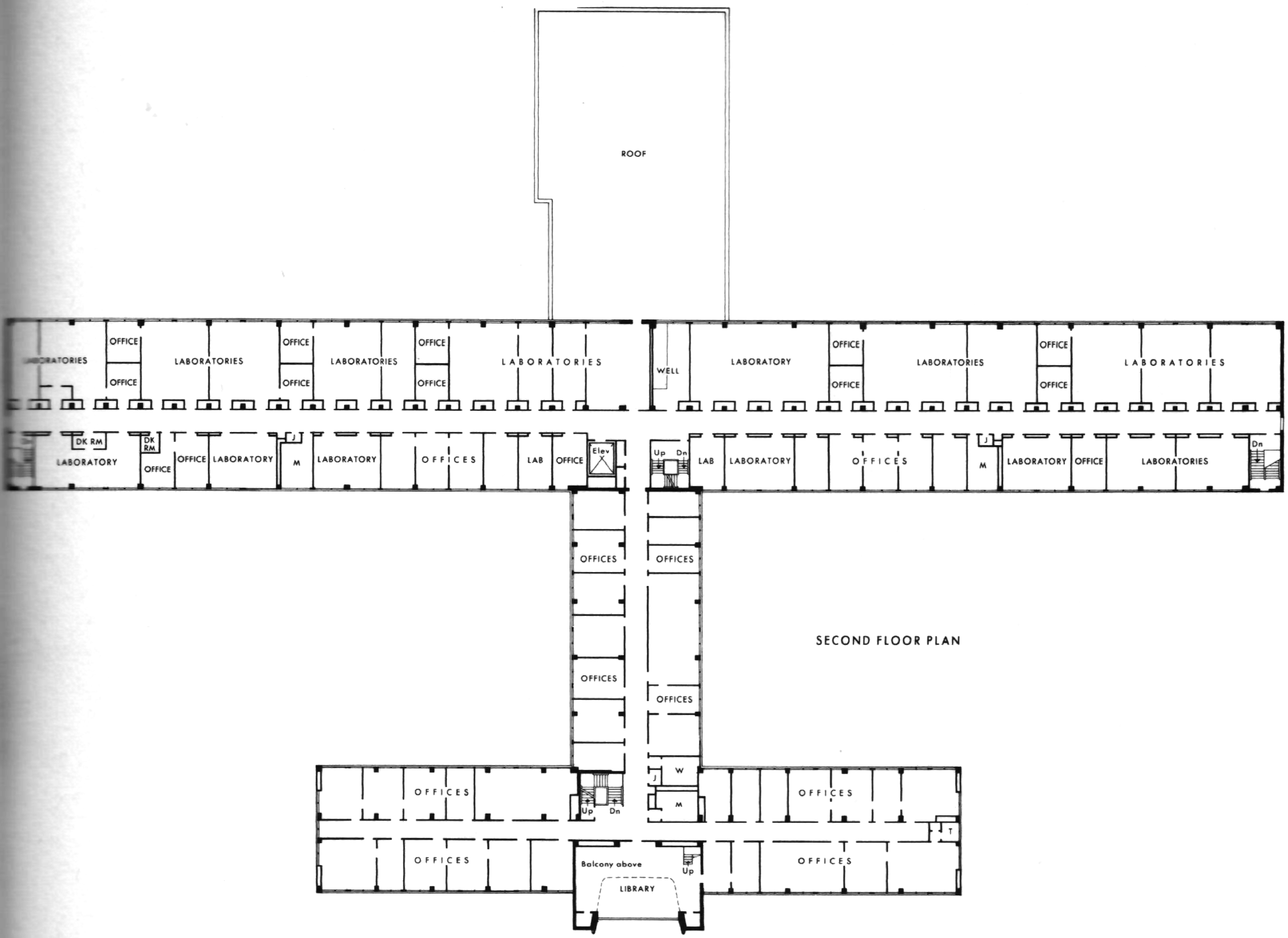
Research Center
Pan American Petroleum Corporation
Tulsa, Oklahoma

Architects:	Shreve, Lamb, and Harmon Associates New York City, New York
Completed:	June 1953
Gross Area of Building:	121,514 sq. ft.
Total Cost of Building:	Not available.
Air Conditioning:	Carrier Weathermaster system, plus individual units in lobby, cafeteria and shops. The Carrier Weathermaster system circulates 40° F water whenever outside temperatures are above 55° F. In winter the thermostat action is reversed while 100° to 190° water is circulated through the radiator coils. Exact water temperature depends on outside temperature. Chilling and heating is done in separate building to keep down noise level. A total of 700 tons of air conditioning is available.

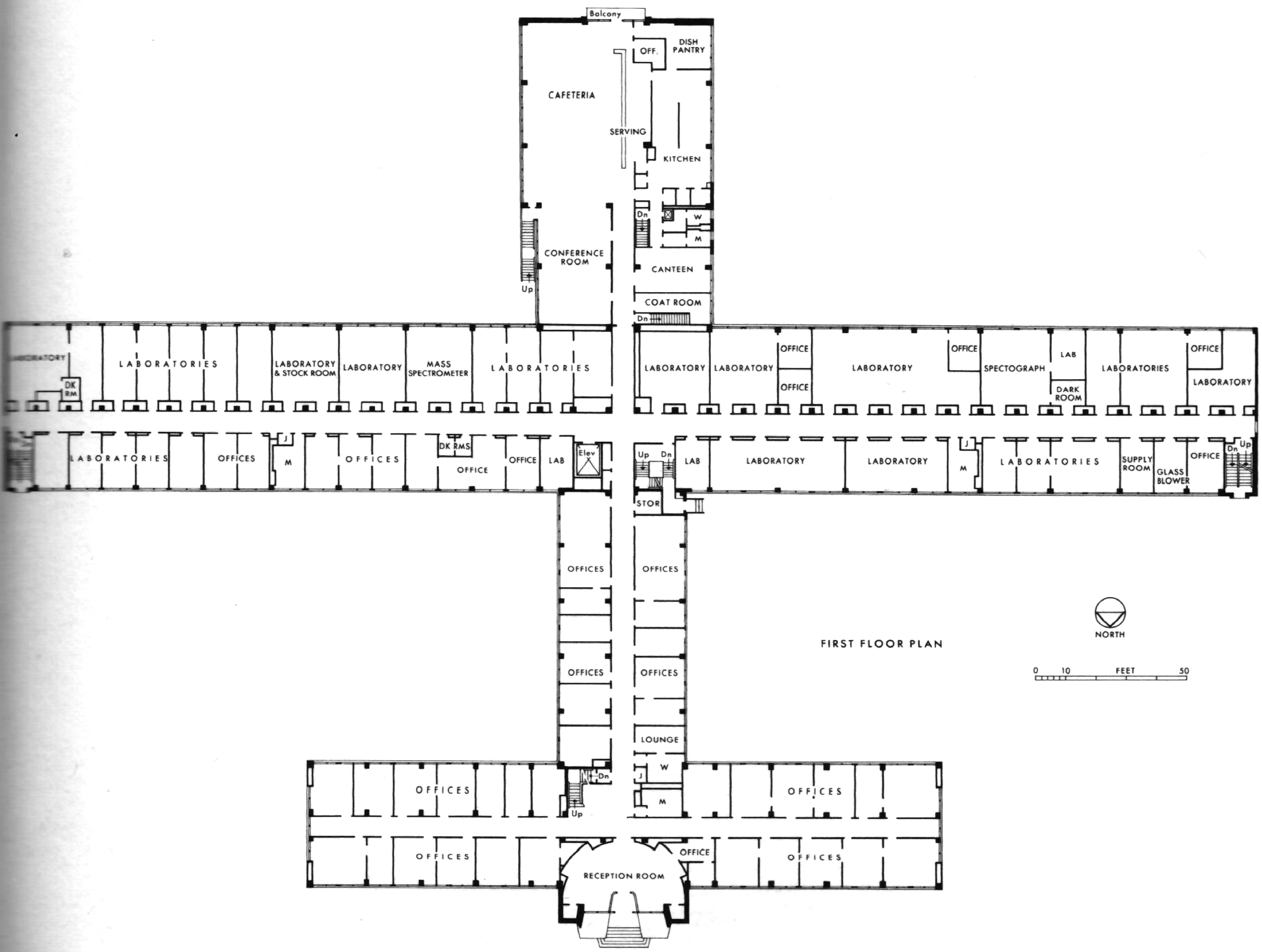
View from southwest. Wing at right has garage on first floor, and cafeteria with kitchen on second floor.


GARAGE
OFFICE
OFFICE
Up
KITCHEN SUPPLIES
Up
Up
Up
LABORATORY
TEST ROOM
LAB
OFFICE
OFFICE
WIRING SHOP
TOOL ROOM
MACHINE SHOP
WELDING SHOP
MECHANICAL EQUIPMENT
STOREROOM
LABORATORIES
LABORATORY
OFFICE
OFFICE
LAB
DARK ROOM
LAB
Up
STOR
LAB
STOR
J
M
OFFICE
MECHANICAL EQUIP
Elev
Up
LAB
SWITCHBOARD ROOM
MECHANICAL EQUIP
DK RM
LAB
J
M
OFFICES
LABORATORY
Up
STOR
OFFICE
LOCKERS
DRAFTING
OFFICE
OFFICE
STORAGE
SAFETY OFFICE
PRINT ROOM & FILES
FIRST AID
T
OFF.
W
J
DARK RM
Up
M
EXPLORATION ACTIVE STORAGE
PRODUCTION ACTIVE STORAGE
RECORD STORAGE
VAULT
MECHANICAL EQUIPMENT
TELEPHONE EQUIP

GROUND FLOOR PLAN


ROOF
LABORATORIES
OFFICE
OFFICE
LABORATORIES
OFFICE
OFFICE
LABORATORIES
OFFICE
OFFICE
LABORATORIES
WELL
LABORATORY
OFFICE
OFFICE
LABORATORIES
OFFICE
OFFICE
LABORATORIES
DK RM
LABORATORY
DK RM
OFFICE
OFFICE
LABORATORY
J
M
LABORATORY
OFFICES
LAB
OFFICE
Elev
Up
Dn
LAB
LABORATORY
OFFICES
J
M
LABORATORY
OFFICE
LABORATORIES
Dn
OFFICES
OFFICES
OFFICES
OFFICES
W
J
M
OFFICES
Up
Dn
OFFICES
T
OFFICES
Balcony above
Up
LIBRARY
OFFICES

SECOND FLOOR PLAN

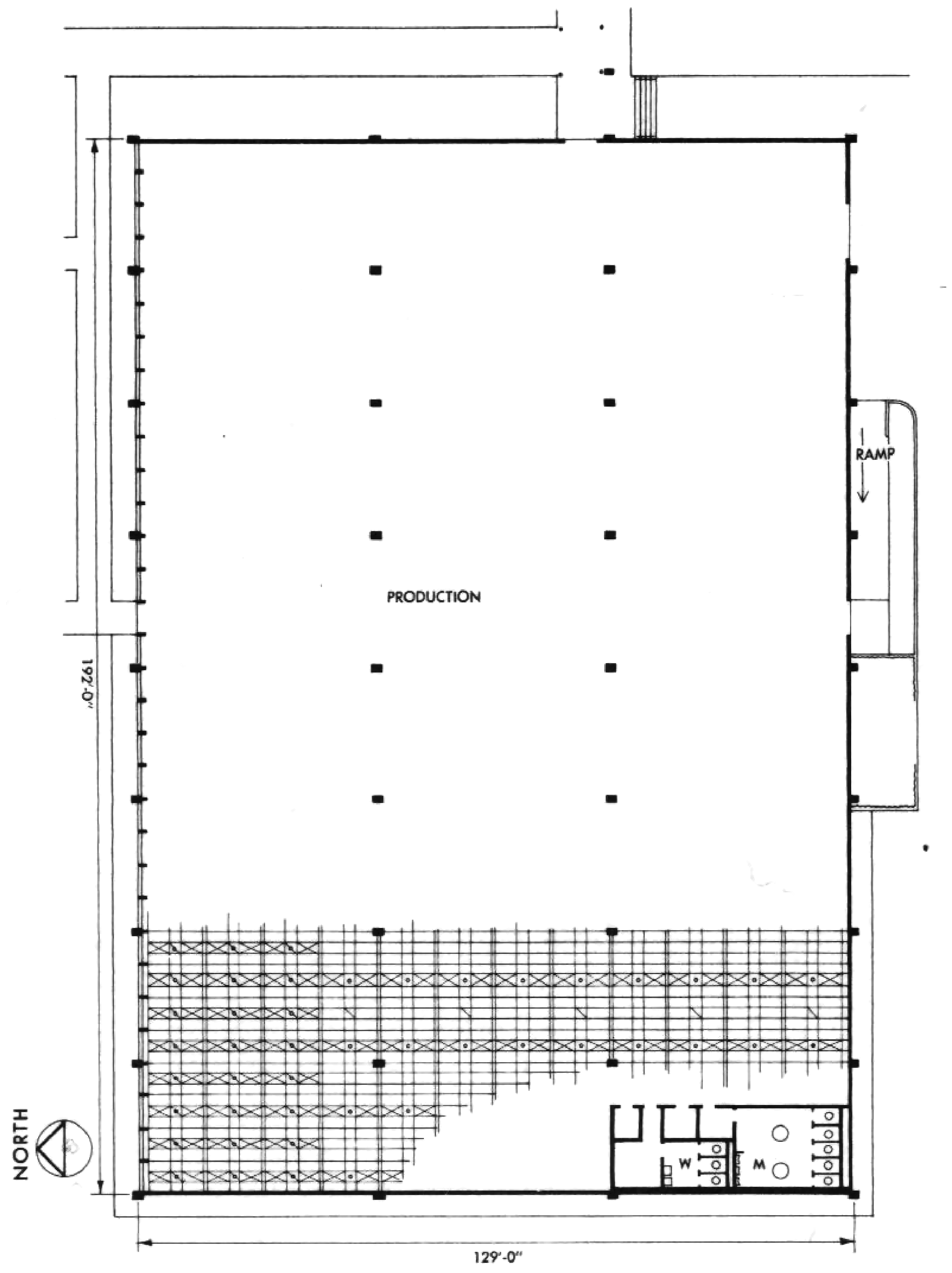

Balcony
OFF.
DISH PANTRY
CAFETERIA
SERVING
KITCHEN
Dn
W
M
CONFERENCE ROOM
Up
CANTEEN
COAT ROOM
Dn
LABORATORY
LABORATORIES
DK RM
LABORATORY & STOCK ROOM
LABORATORY
MASS SPECTROMETER
LABORATORIES
LABORATORY
LABORATORY
OFFICE
OFFICE
LABORATORY
OFFICE
SPECTOGRAPH
LAB
DARK ROOM
LABORATORIES
OFFICE
LABORATORY
LABORATORIES
OFFICES
J
M
OFFICES
DK RMS
OFFICE
OFFICE
LAB
Elev
Up
Dn
LAB
LABORATORY
LABORATORY
J
M
LABORATORIES
SUPPLY ROOM
GLASS BLOWER
OFFICE
Dn
Up
STOR
OFFICES
OFFICES
OFFICES
OFFICES
LOUNGE
Dn
W
J
M
Up
OFFICES
OFFICES
OFFICES
OFFICE
OFFICES
RECEPTION ROOM
NORTH
0
10
FEET
50

FIRST FLOOR PLAN

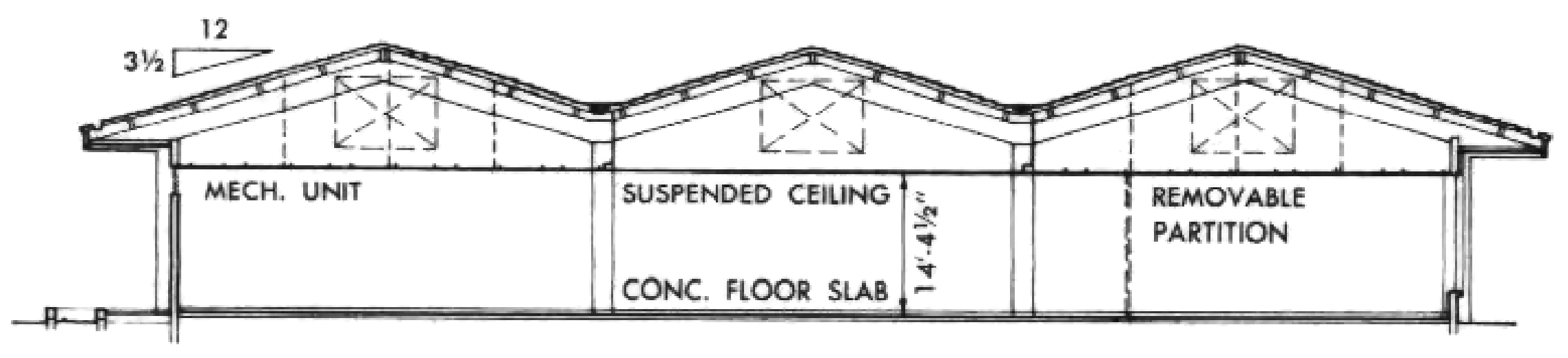
29.

Klystron Research and Development Building #1, Addition 2, Power Tube Test Building #6
Varian Associates
Palo Alto, California

Architects:	Michael A. Gallis San Francisco, California
Completed:	Bldg. #1, Addition 2, June 1960 Bldg. #6 Sept. 1958
Gross Area of Building:	Bldg. #1, Addition 2—25,000 sq. ft. Attic 25,000 sq. ft. Bldg. #6 3,500 sq. ft.
Total Cost of Building:	Bldg. #1, Addition 2—$375,000 Bldg. #6 110,000
Air Conditioning:	None. However ventilating system designed for future cooling coils in air handling equipment.

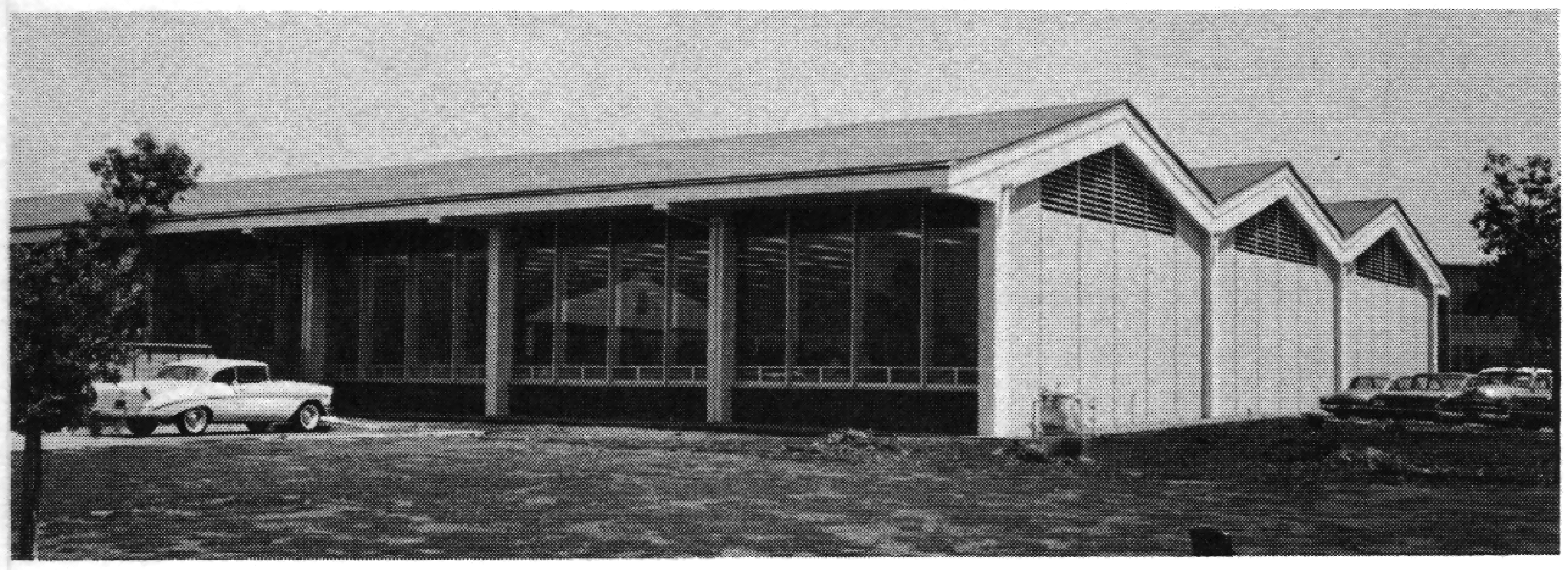

RAMP
PRODUCTION
192'-0"
NORTH
W
M
129'-0"

FLOOR PLAN


12
3½
MECH. UNIT
SUSPENDED CEILING
14'-4½"
CONC. FLOOR SLAB
REMOVABLE PARTITION

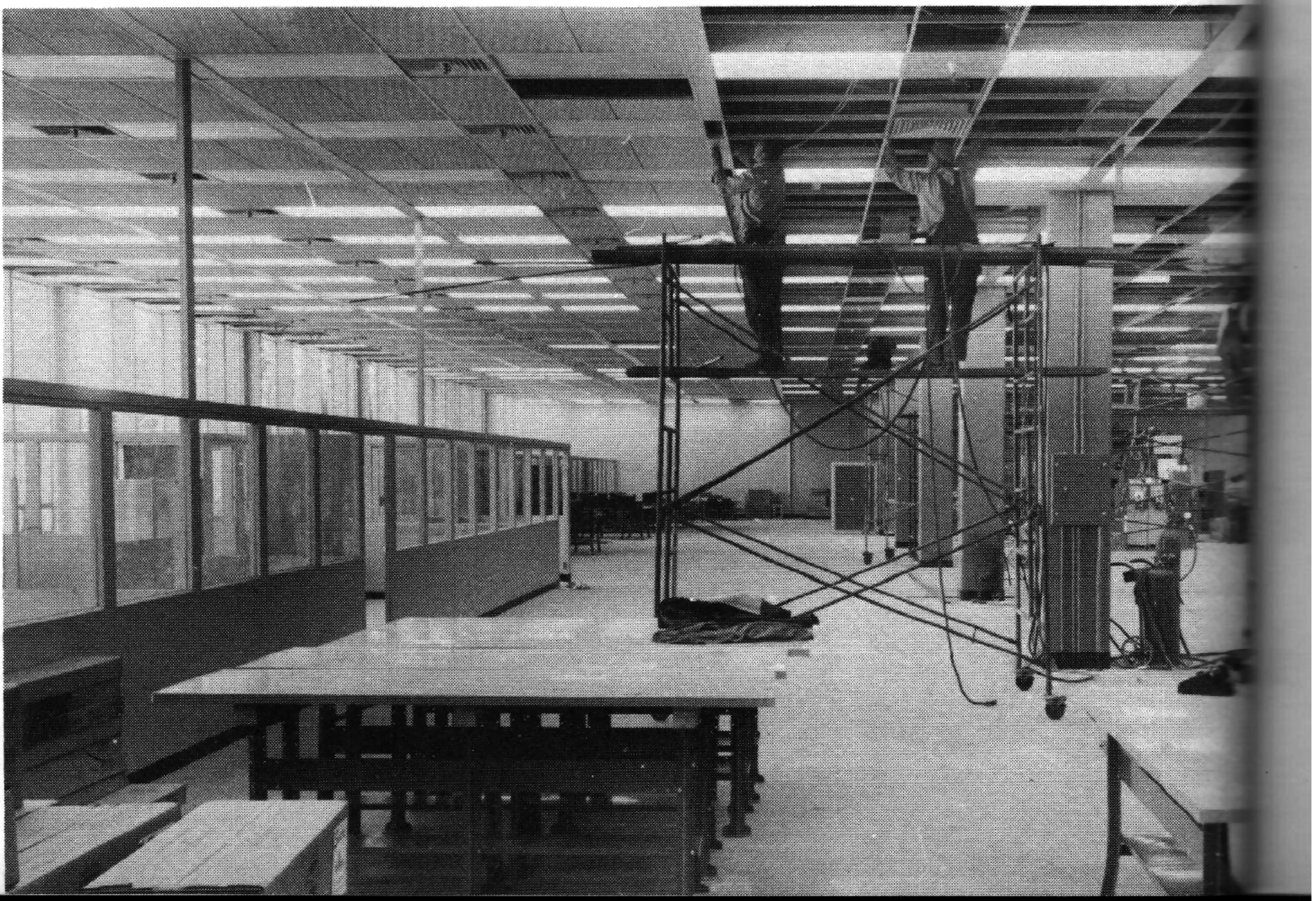
TRANSVERSE SECTION

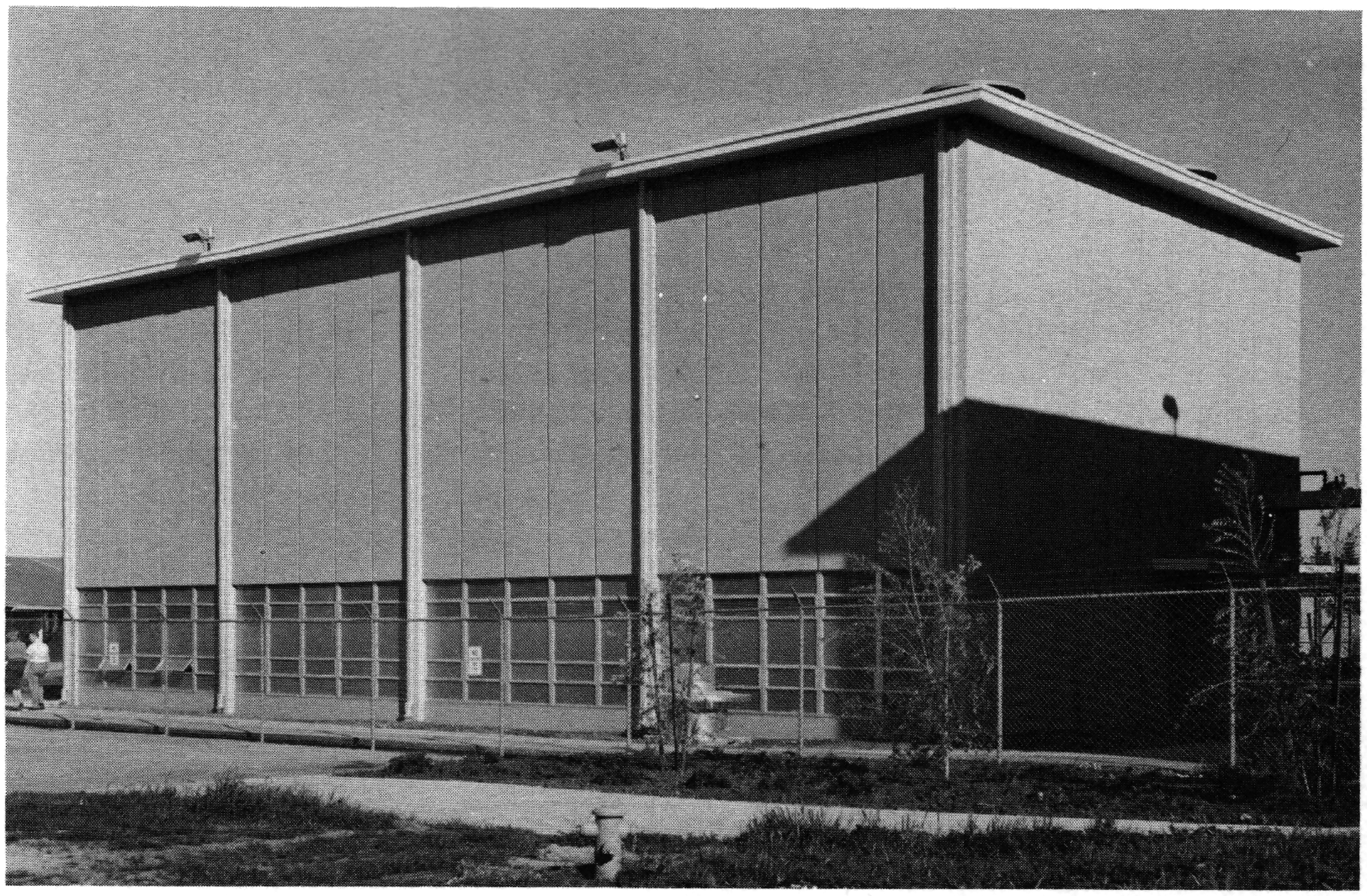
BUILDING #1



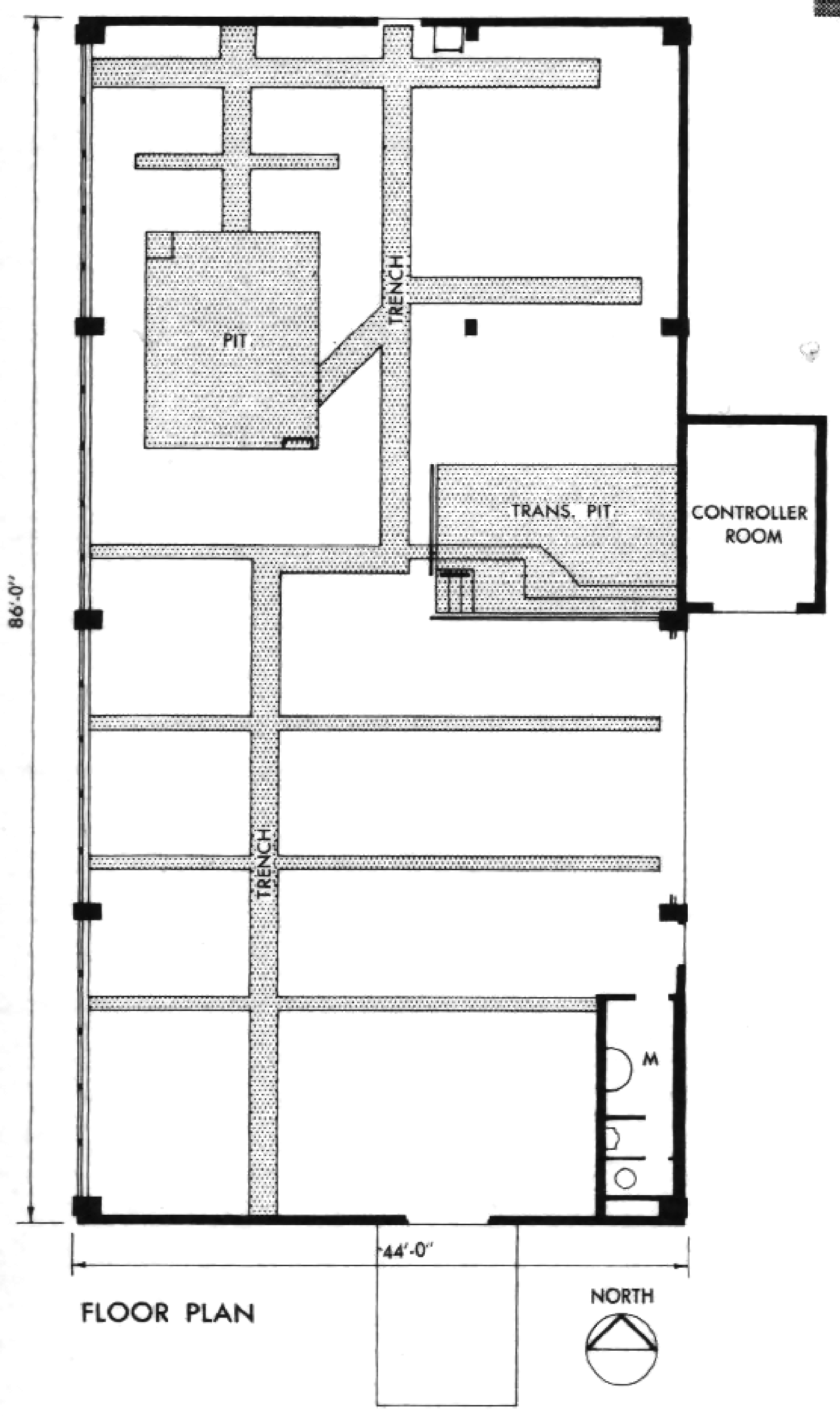
View of north elevation showing precast bents which form columns and sloping roof beams. The roof is finished with asbestos shingles on timber. The ceiling is a flat suspended system as shown below.

Suspended modular ceiling on 2-by-4-foot grid combines lighting, acoustical treatment, and ventilation with 6-inch wide aluminum plates for penetration of service lines, including electrical power. All items are interchangeable.



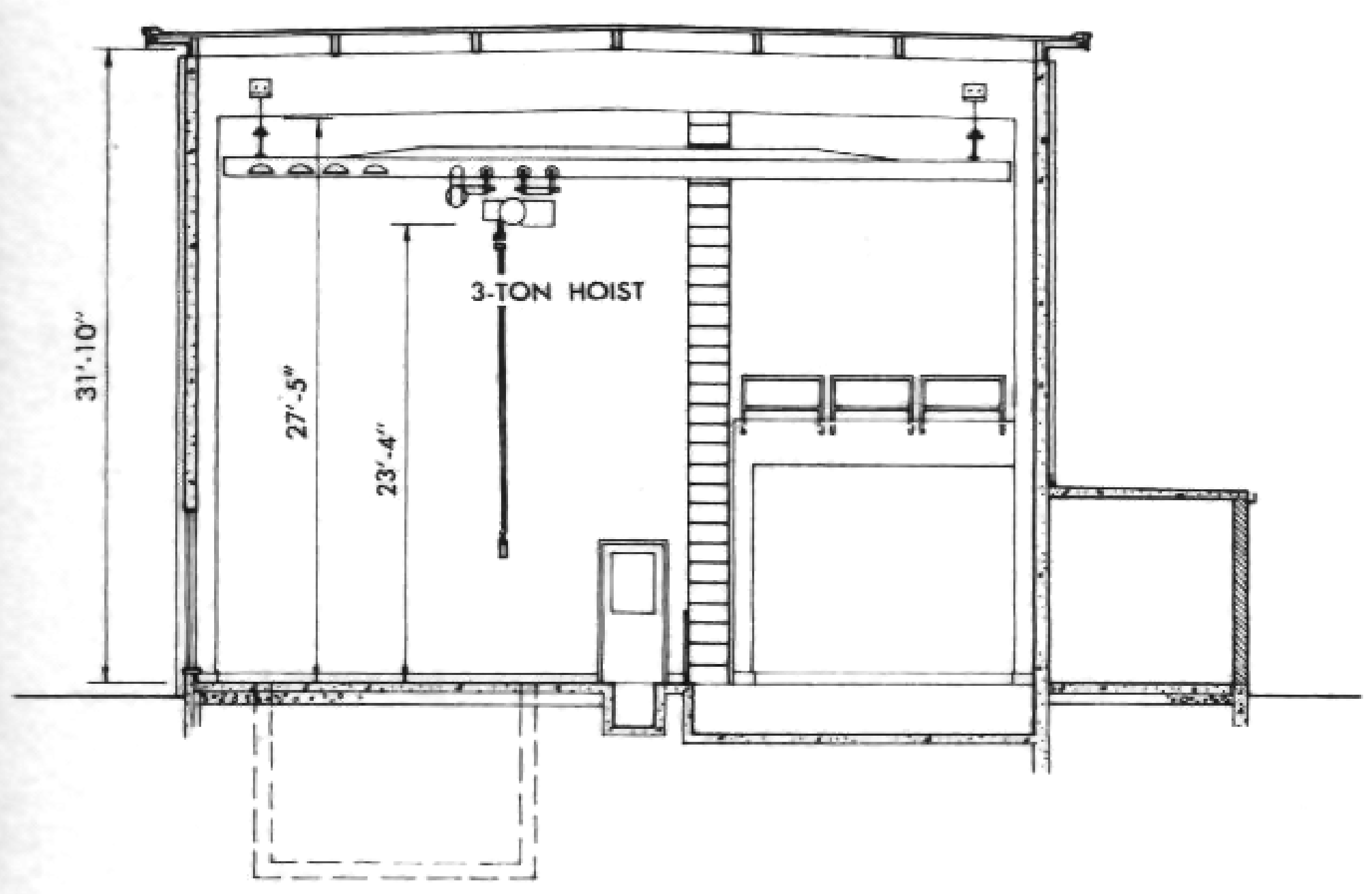


Small high bay industrial building with flat roof. Such high bays with cranes are occasionally needed for handling research components. Super klystrons 12 to 14 feet long are handled here.

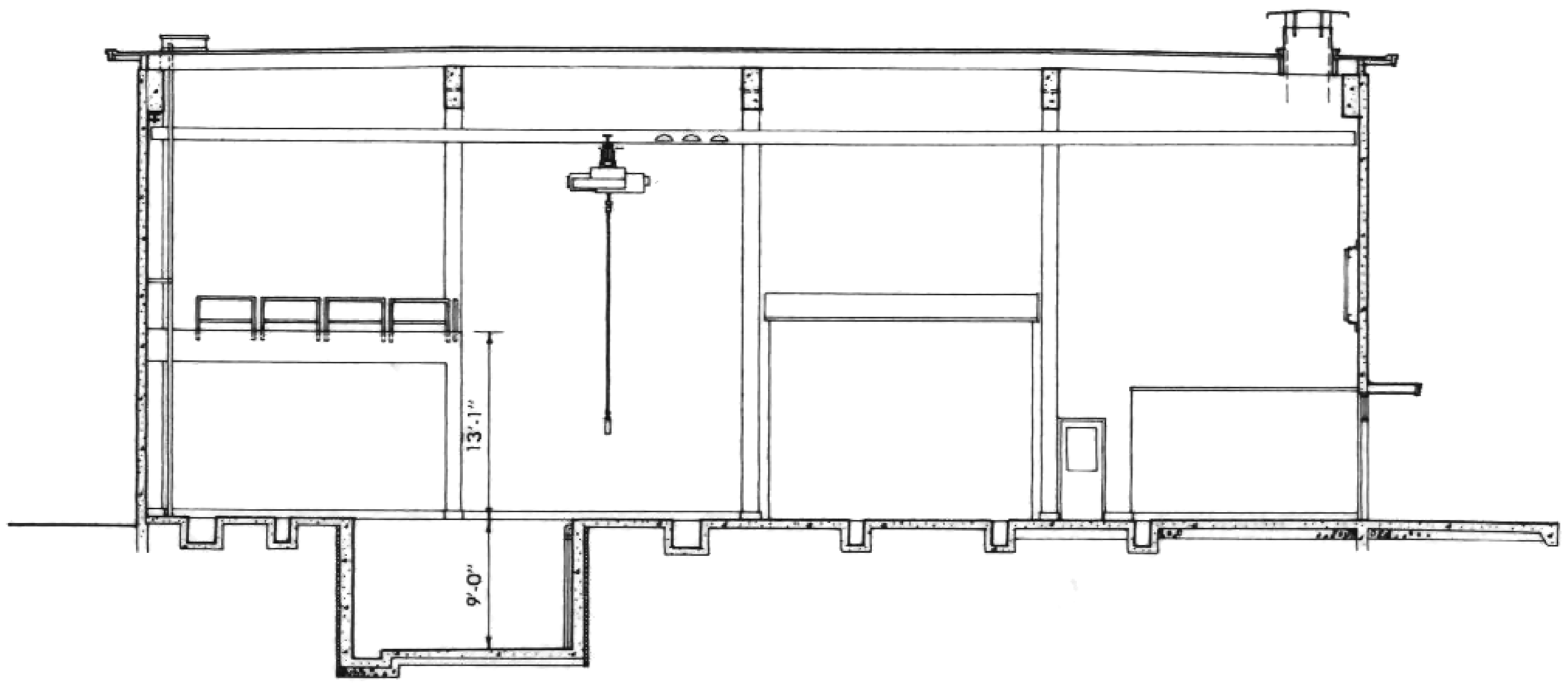

PIT
TRENCH
TRANS. PIT
CONTROLLER ROOM
86'-0"
TRENCH
M
44'-0"
NORTH

FLOOR PLAN

BUILDING #6


31'-10"
27'-5"
23'-4"
3-TON HOIST

SECTION



LONGITUDINAL SECTION

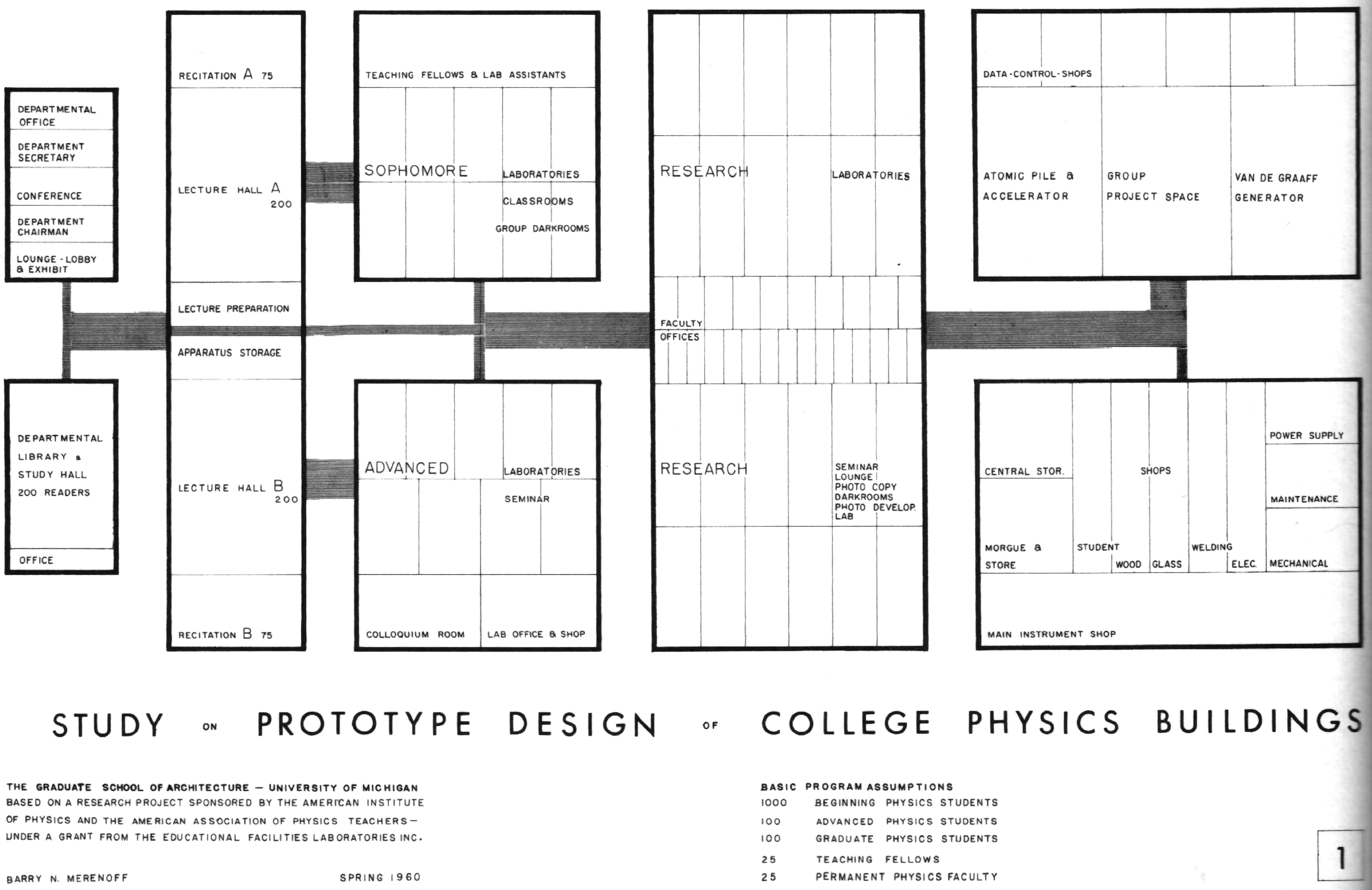
30.

Study on Prototype Design of College Physics Buildings

by Barry N. Merenoff

Seldom does an architectural student take the opportunity to engage in architectural research. He is most often discouraged by the disproportionate amount of reading, analyzing and conferring required in preparation for the final architectural development.

I was originally attracted to this project by the long-run importance of scientific training and education to our national defense. My interest developed further as I became acquainted with the research and technical staff of Randall Laboratories at the University of Michigan. Four of these men were selected to serve as my consultants. The group included: the chairman of the Physics Department, Professor Dennison, who was in charge of the over-all program and concept; Professor McCormick, who was concerned with the Sophomore Laboratories; Professor Hazen, who was concerned with the Advanced and Research Laboratories; and the head of lecture preparation,

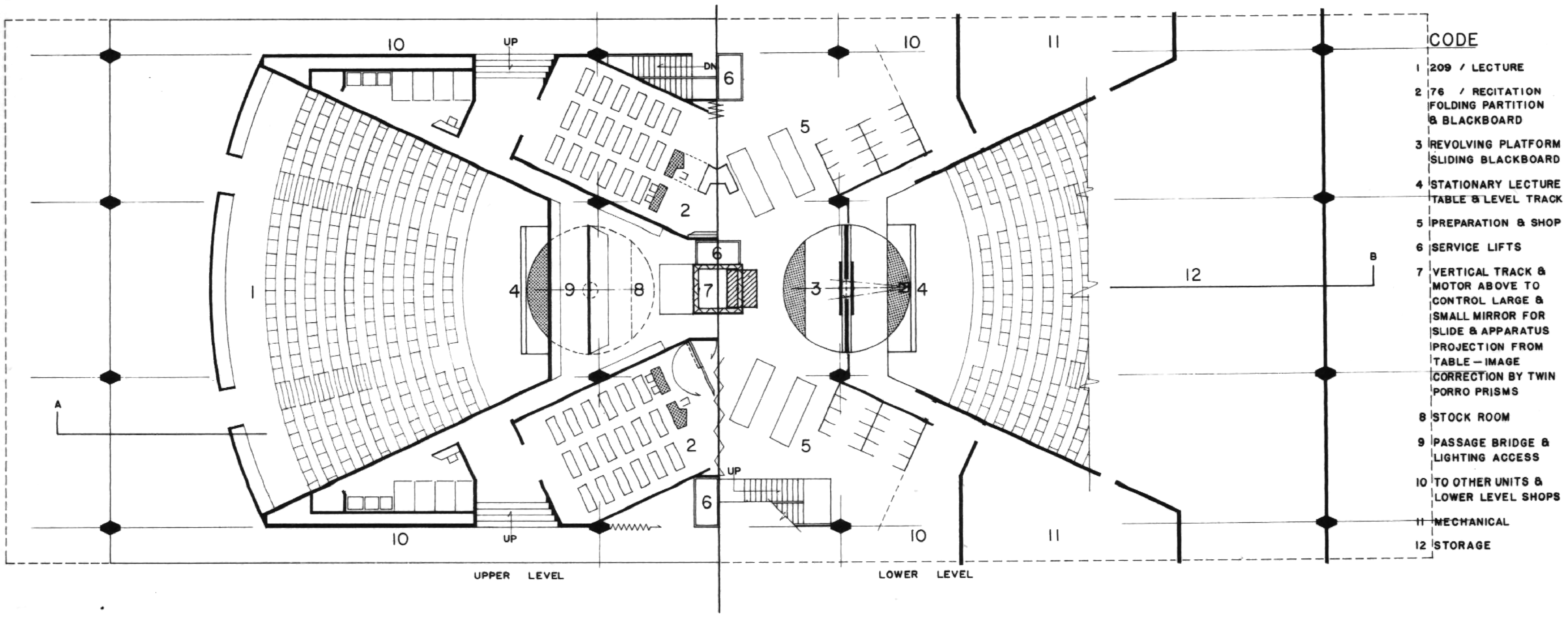

DEPARTMENTAL OFFICE
DEPARTMENT SECRETARY
CONFERENCE
DEPARTMENT CHAIRMAN
LOUNGE - LOBBY & EXHIBIT
DEPARTMENTAL LIBRARY & STUDY HALL 200 READERS
OFFICE
RECITATION A 75
LECTURE HALL A 200
LECTURE PREPARATION
APPARATUS STORAGE
LECTURE HALL B 200
RECITATION B 75
TEACHING FELLOWS & LAB ASSISTANTS
SOPHOMORE
LABORATORIES
CLASSROOMS
GROUP DARKROOMS
ADVANCED
LABORATORIES
SEMINAR
COLLOQUIUM ROOM
LAB OFFICE & SHOP
RESEARCH
LABORATORIES
FACULTY OFFICES
RESEARCH
SEMINAR
LOUNGE
PHOTO COPY
DARKROOMS
PHOTO DEVELOP. LAB
DATA-CONTROL-SHOPS
ATOMIC PILE & ACCELERATOR
GROUP PROJECT SPACE
VAN DE GRAAFF GENERATOR
CENTRAL STOR.
SHOPS
POWER SUPPLY
MAINTENANCE
MORGUE & STORE
STUDENT
WOOD
GLASS
WELDING
ELEC.
MECHANICAL
MAIN INSTRUMENT SHOP
STUDY ON PROTOTYPE DESIGN OF COLLEGE PHYSICS BUILDINGS
THE GRADUATE SCHOOL OF ARCHITECTURE — UNIVERSITY OF MICHIGAN
BASED ON A RESEARCH PROJECT SPONSORED BY THE AMERICAN INSTITUTE OF PHYSICS AND THE AMERICAN ASSOCIATION OF PHYSICS TEACHERS — UNDER A GRANT FROM THE EDUCATIONAL FACILITIES LABORATORIES INC.
BARRY N. MERENOFF
SPRING 1960
BASIC PROGRAM ASSUMPTIONS
1000 BEGINNING PHYSICS STUDENTS
100 ADVANCED PHYSICS STUDENTS
100 GRADUATE PHYSICS STUDENTS
25 TEACHING FELLOWS
25 PERMANENT PHYSICS FACULTY
1

Mr. Dockrill, who dealt with the lecture halls, preparation areas, and shop areas.

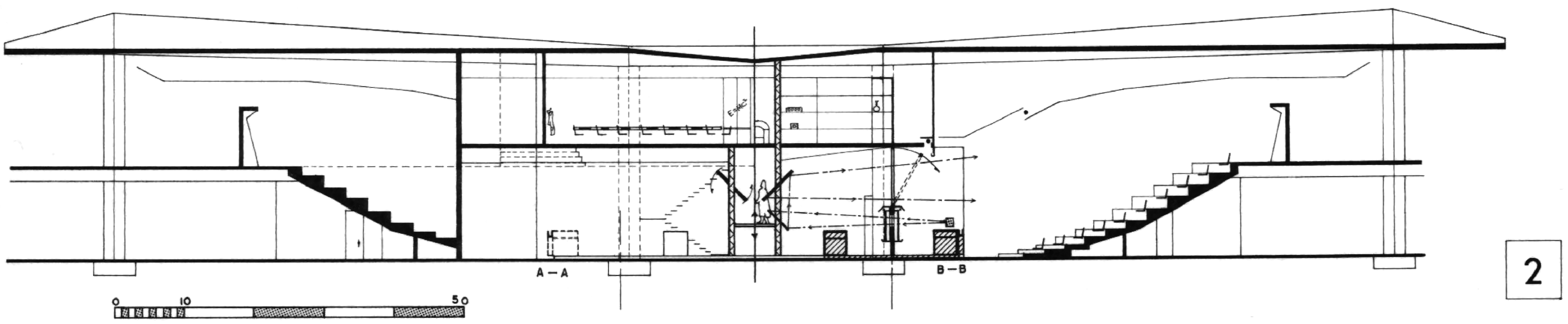
The first series of individual conferences dealt with the development of a prototype program, aimed at satisfying the needs of an average American college. As we felt that adequate research facilities were necessary to attract a well-qualified staff, we emphasized this aspect of the program. The basic concept also included separating the teaching spaces from the faculty offices, and integrating the offices with the research facilities. These early conferences were often recorded and were carefully analyzed at a later time. Later conferences dealt directly with individual room units, and made use of preliminary drawings which I had prepared. More than half the school semester was thus devoted to conferences and research.

The ideas of the men at Randall and my own suggestions were explored from the architectural point of view. For example, one of Mr. Dockrill's ideas was the revolving lecture platform. This concept provides for two identical sets of lecture tables and blackboards for each lecture hall. While one set is in use, the other is being prepared for the following lecture session.

The expanded service core is my own suggestion for the particular flexibility problems of the physicists. Work tables can "plug in" to movable power panels when required. Air, gas, water, and power lines, as well as air ducts, can be arranged as desired within the structure-free core. A sink, a writing surface, a fume vent hood, or storage cabinets, can be quickly set up between the power panels by the use of movable floor grates. All of


10
UP
10
11
6
DN
5
2
1
4
9
8
7
3
4
12
B
A
2
5
6
UP
10
UP
10
11
UPPER LEVEL
LOWER LEVEL
CODE
1 209 / LECTURE
2 76 / RECITATION FOLDING PARTITION & BLACKBOARD
3 REVOLVING PLATFORM SLIDING BLACKBOARD
4 STATIONARY LECTURE TABLE & LEVEL TRACK
5 PREPARATION & SHOP
6 SERVICE LIFTS
7 VERTICAL TRACK & MOTOR ABOVE TO CONTROL LARGE & SMALL MIRROR FOR SLIDE & APPARATUS PROJECTION FROM TABLE — IMAGE CORRECTION BY TWIN PORRO PRISMS
8 STOCK ROOM
9 PASSAGE BRIDGE & LIGHTING ACCESS
10 TO OTHER UNITS & LOWER LEVEL SHOPS
11 MECHANICAL
12 STORAGE

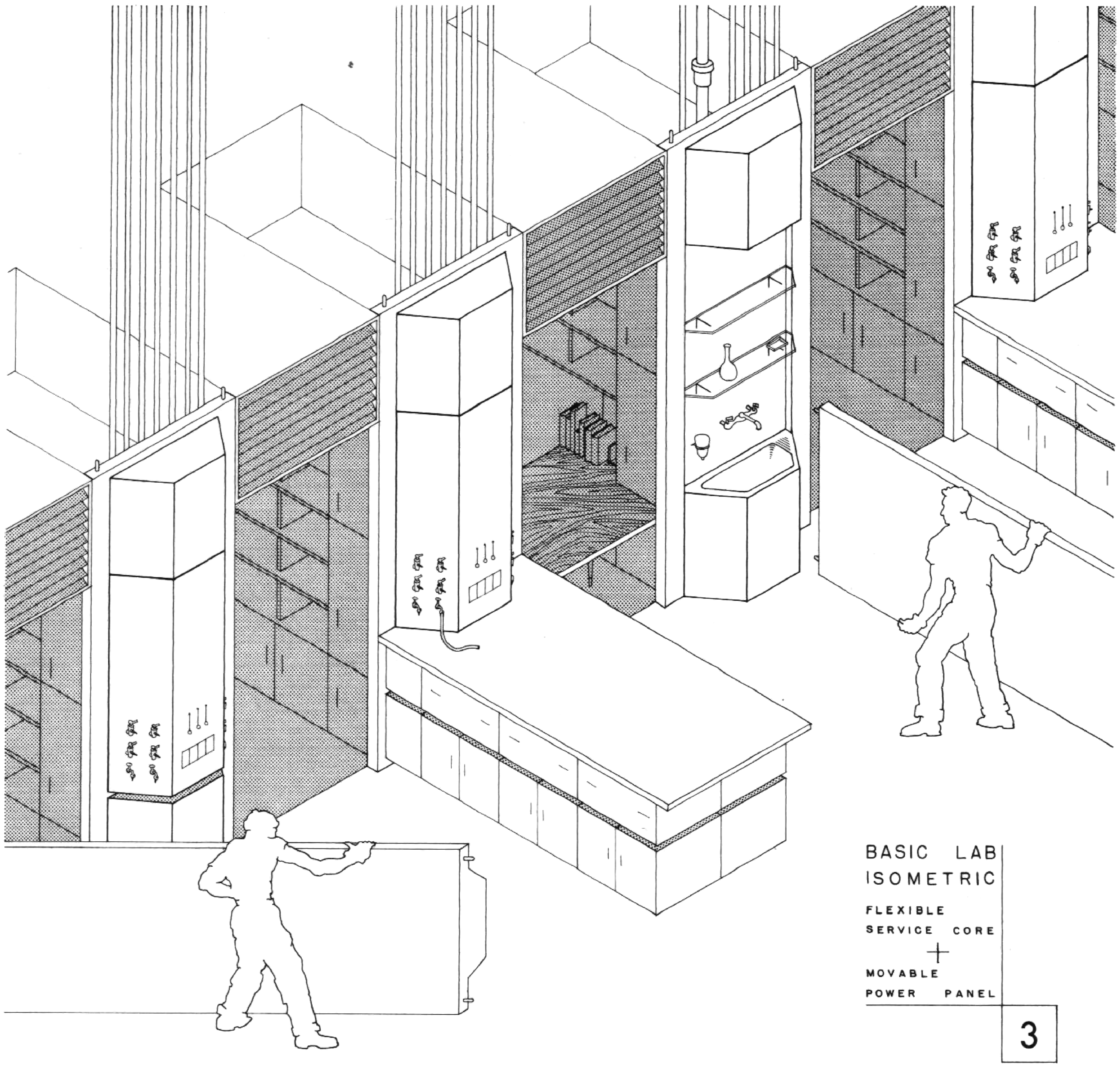
BASIC LECTURE & RECITATION GROUPING



2

30. (Continued)

Study on Prototype Design



the ideas expressed in this study were not original; however, they are here applied to an architectural solution, to be judged and evaluated as part of a total concept.

There are five steps in the architectural approach:

1. To concentrate on basic concepts for the lecture hall grouping and the three types of laboratories (Sophomore, Advanced, and Research).
2. To develop prototype groupings of the laboratories and their related spaces.
3. To combine these prototype groups with the lecture hall, library, and departmental spaces to form basic building schemes.
4. To study these basic schemes in their mass or block relationships.
5. To develop one scheme in full architectural refinement. (One school semester proved insufficient time to complete this final stage.)

Compactness in the prototype groupings and expandability in the basic building schemes were prime considerations throughout the architectural development.

By no means do we expect to have fully answered all the complex problems involved in this study. We do hope to have generated new and vital thinking among both architects and physicists.

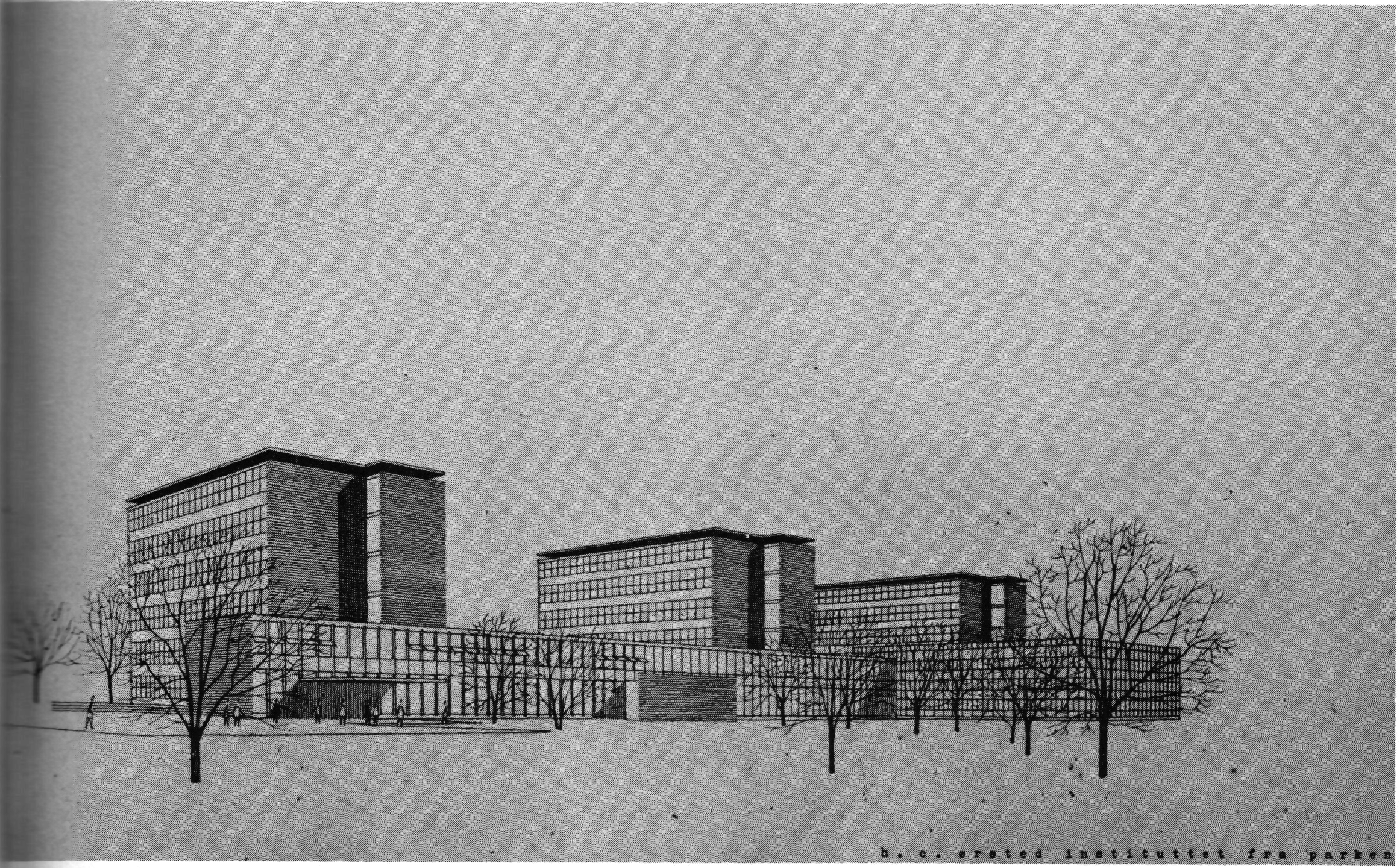
31.

H. C. Oersted Technical Institute
The University of Copenhagen
Copenhagen, Denmark

Architects:	Eva & Nils Koppel, M.A.A. Nils Koppel, Royal Inspector of Public Houses, Lundtoftevej 100, KGS. Lyngby, Denmark
Proposed Completion:	January, 1963
Gross Area of Building:	30,000 sq. meters
Total Cost of Building:	36,000,000 Danish kroner*
Air Conditioning:	None

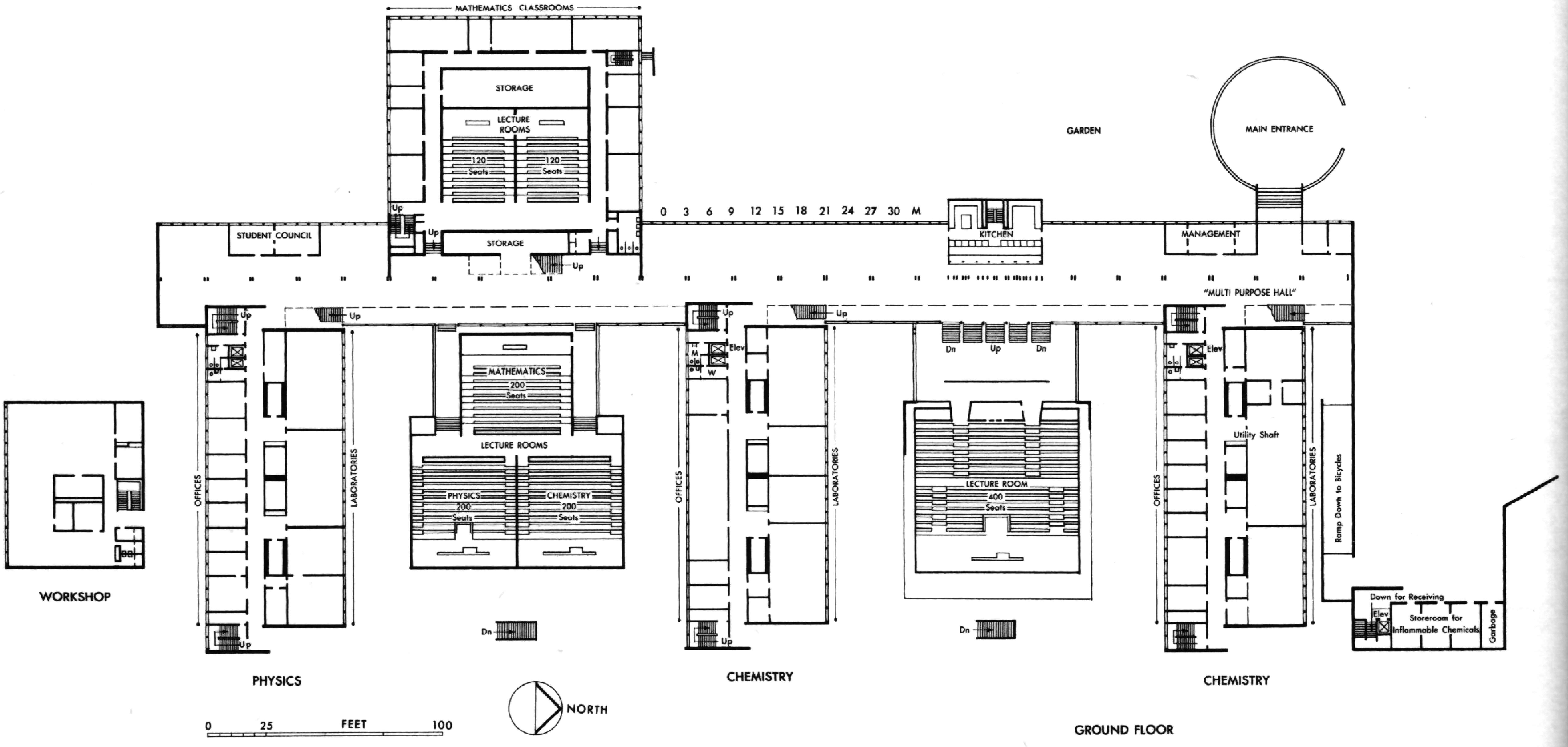
* Includes heating, ventilating, electrical and mechanical services, and laboratory furniture.

Architect's perspective of proposed building. (See following pages for floor plans.)


h. c. ørsted instituttet fra parken

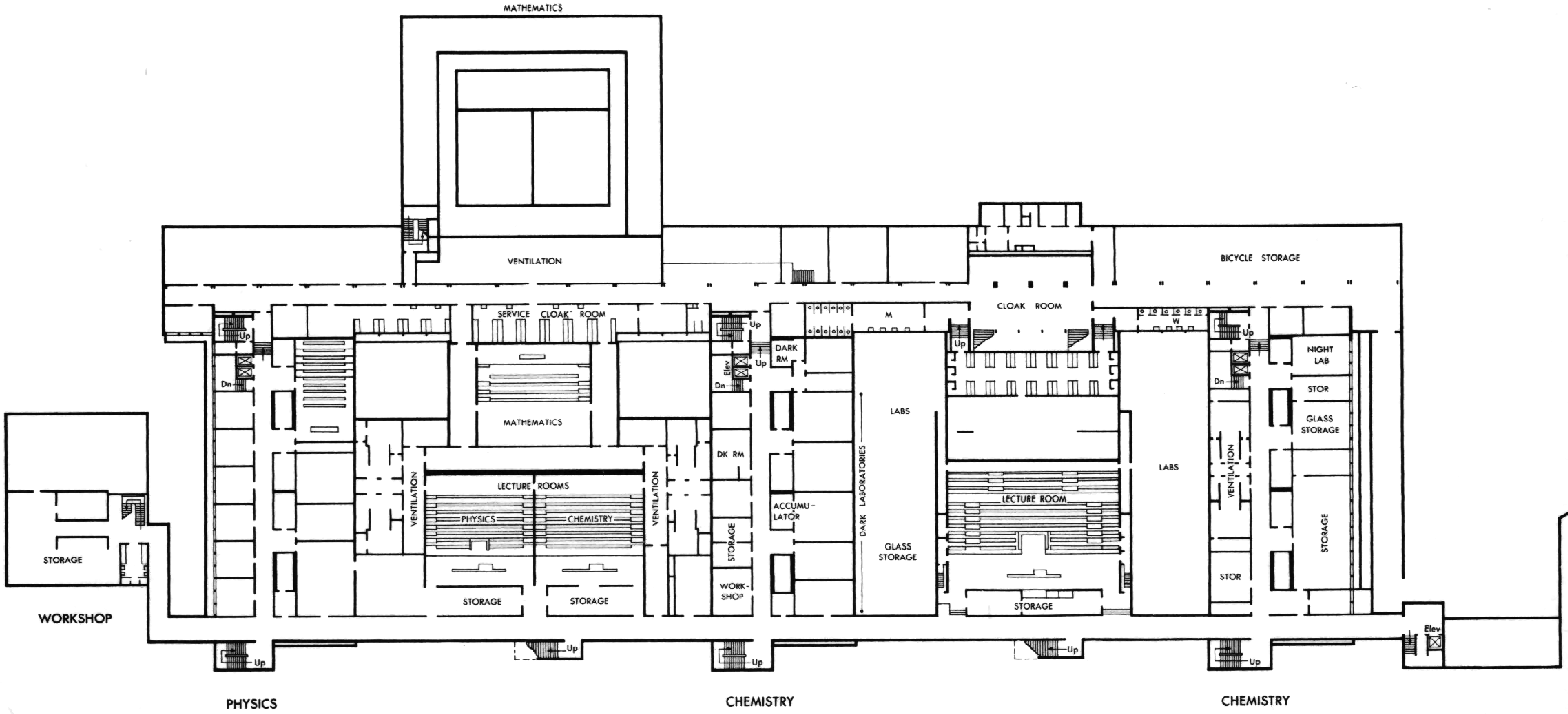
31. (Continued)

H. C. Oersted Technical Institute



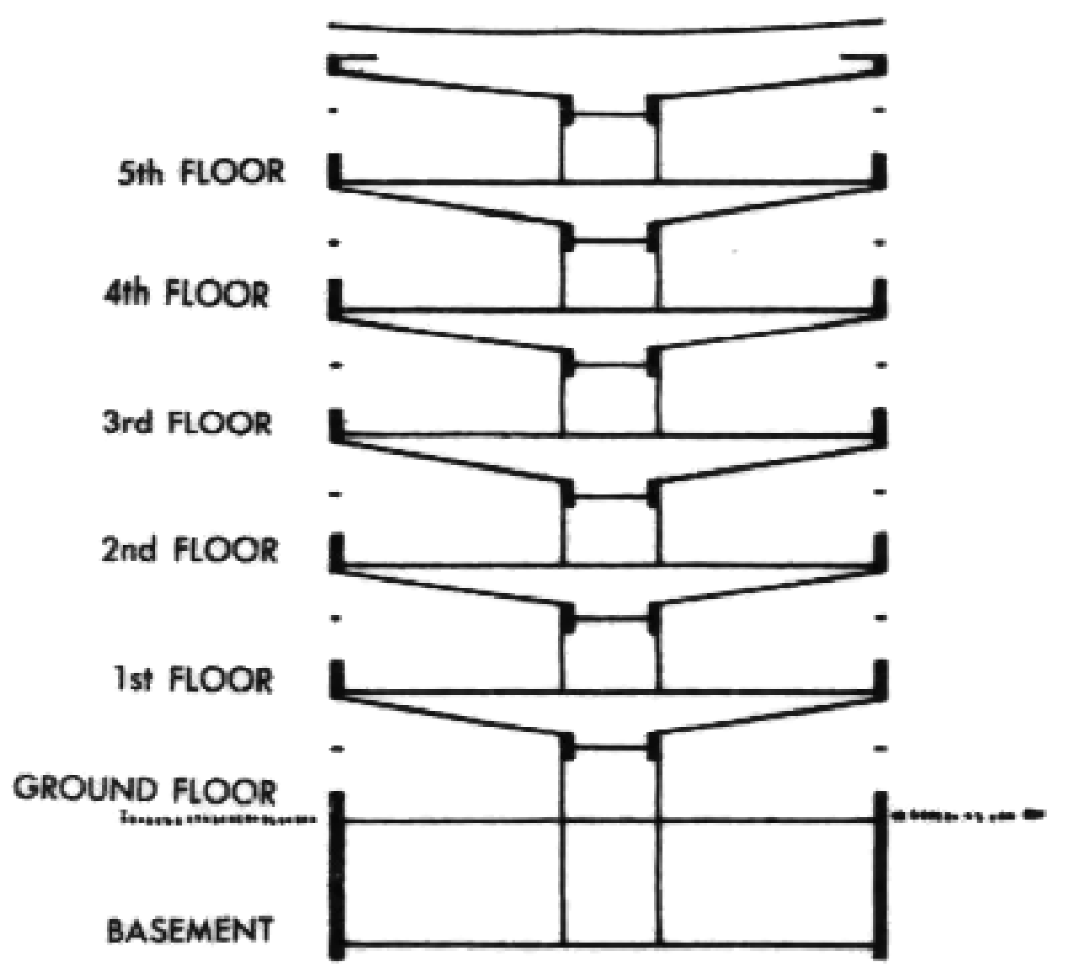
MATHEMATICS CLASSROOMS
STORAGE
LECTURE ROOMS
120 Seats
120 Seats
STORAGE
Up
GARDEN
MAIN ENTRANCE
0 3 6 9 12 15 18 21 24 27 30 M
KITCHEN
STUDENT COUNCIL
MANAGEMENT
"MULTI PURPOSE HALL"
MATHEMATICS 200 Seats
LECTURE ROOMS
PHYSICS 200 Seats
CHEMISTRY 200 Seats
LECTURE ROOM 400 Seats
OFFICES
LABORATORIES
Elev
M
W
Dn
Utility Shaft
Ramp Down to Bicycles
Down for Receiving
Storeroom for Inflammable Chemicals
Garbage
WORKSHOP
PHYSICS
CHEMISTRY
CHEMISTRY
0 25 FEET 100
NORTH

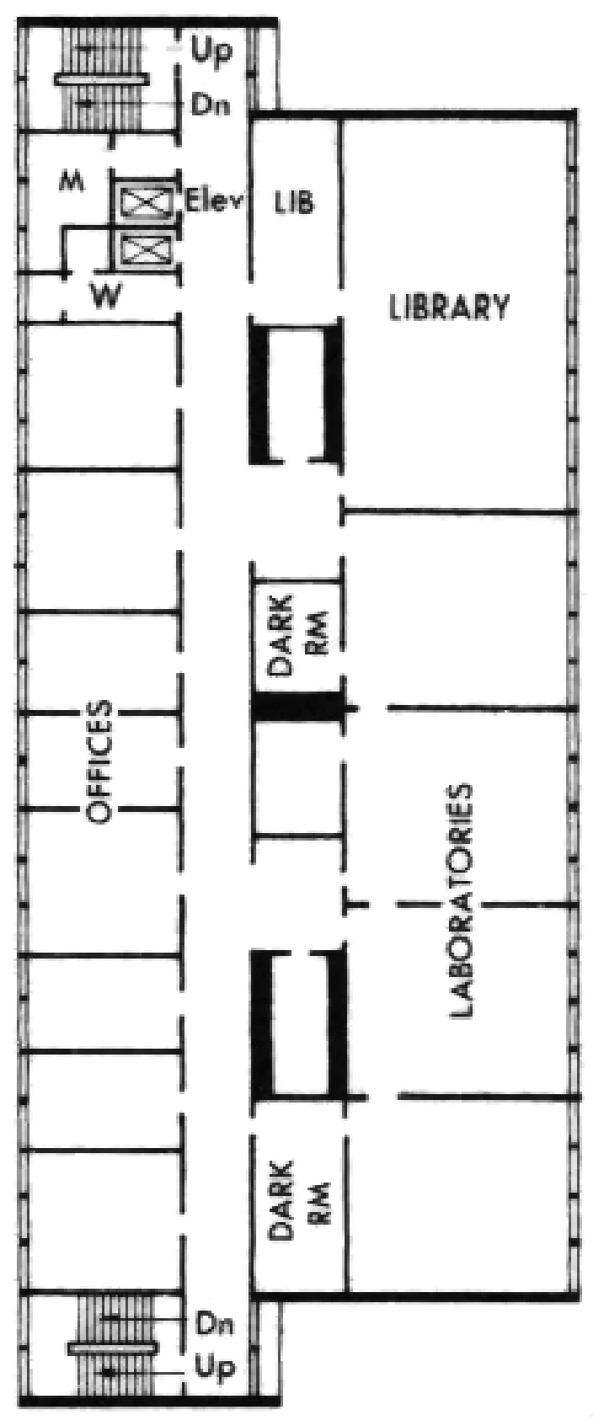
GROUND FLOOR



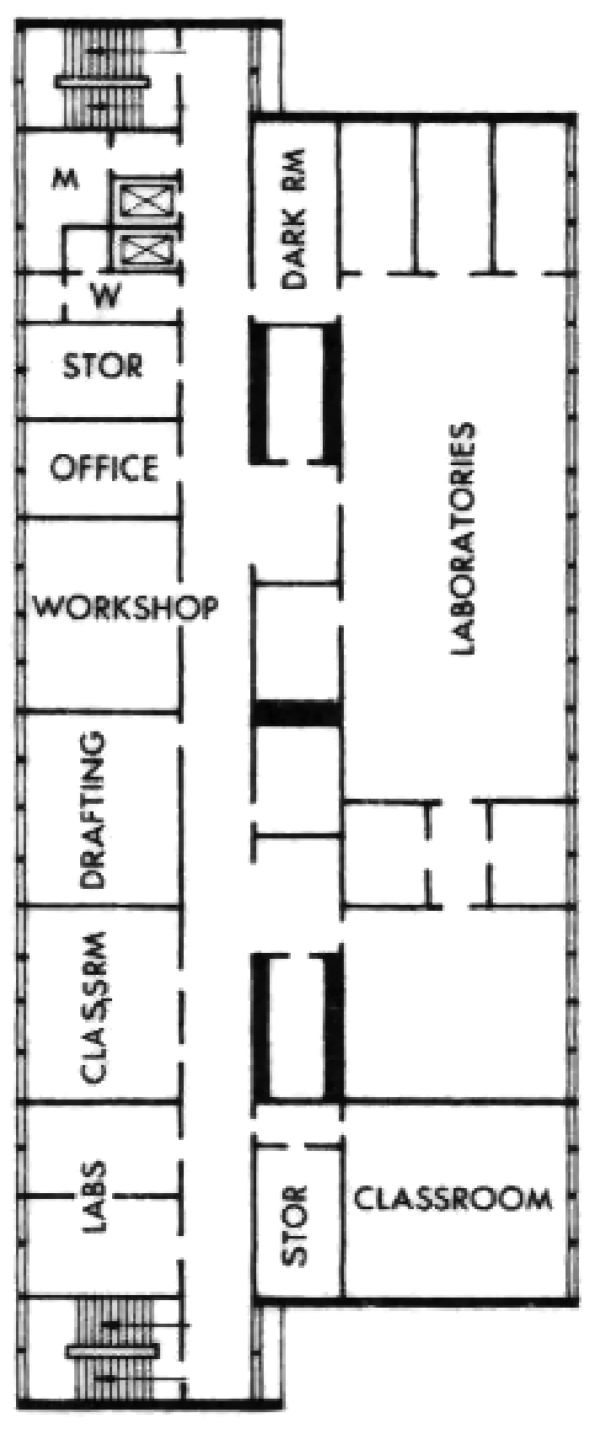
MATHEMATICS
VENTILATION
BICYCLE STORAGE
SERVICE CLOAK ROOM
CLOAK ROOM
M
W
DARK RM
DK RM
NIGHT LAB
STOR
GLASS STORAGE
MATHEMATICS
LABS
LABS
LECTURE ROOMS
PHYSICS
CHEMISTRY
VENTILATION
ACCUMU-LATOR
DARK LABORATORIES
GLASS STORAGE
LECTURE ROOM
STORAGE
WORK-SHOP
STORAGE
STORAGE
STORAGE
STOR
STORAGE
Elev
Up
Dn
WORKSHOP
PHYSICS
CHEMISTRY
CHEMISTRY

BASEMENT FLOOR

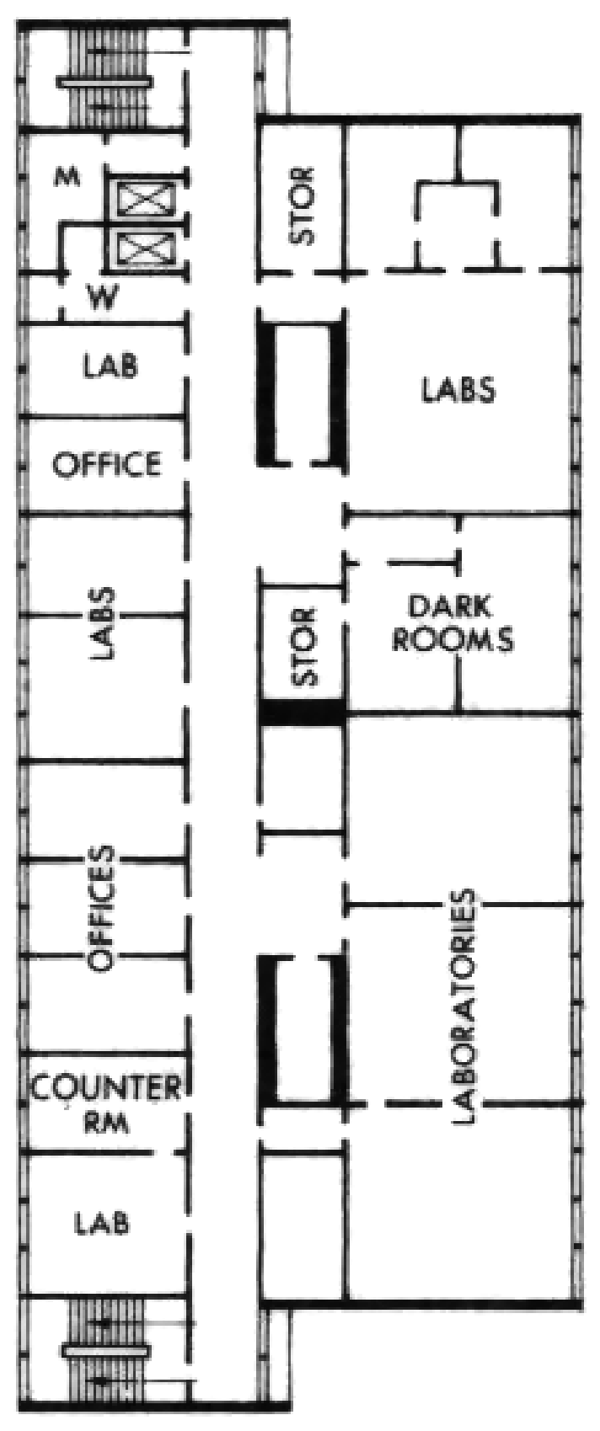

5th FLOOR
4th FLOOR
3rd FLOOR
2nd FLOOR
1st FLOOR
GROUND FLOOR
BASEMENT


Up
Dn
M
Elev
W
LIB
LIBRARY
OFFICES
DARK RM
LABORATORIES
DARK RM
Dn
Up

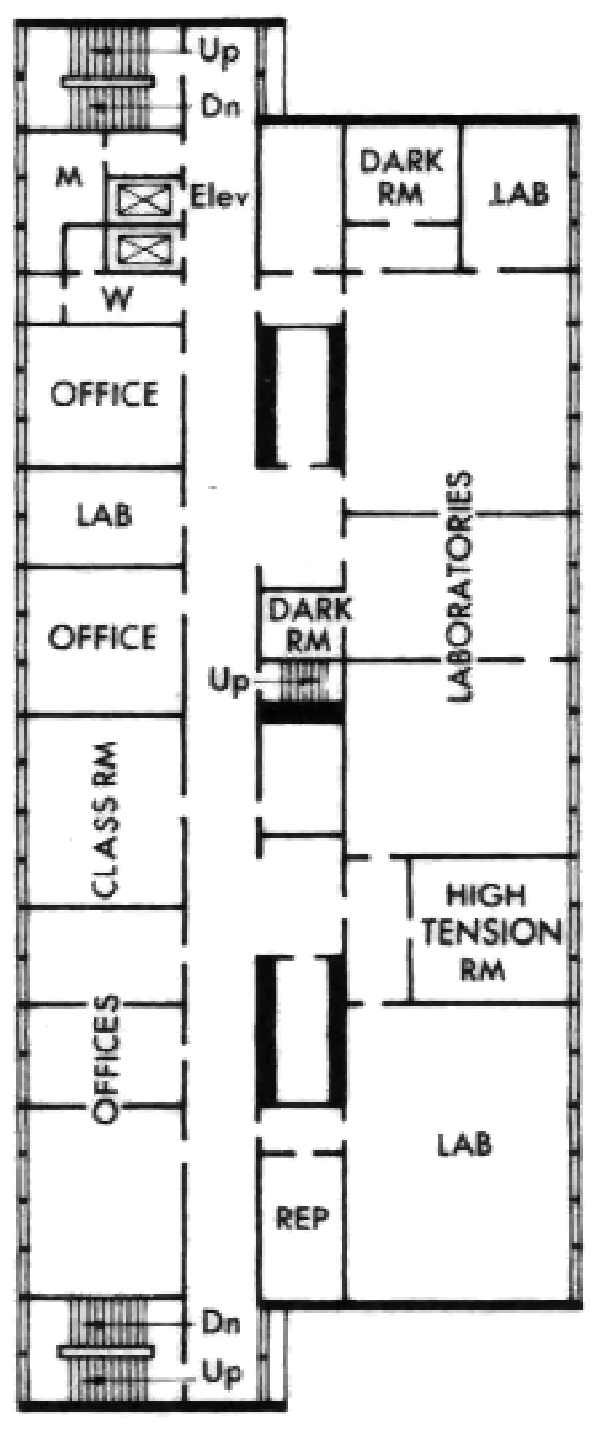
2nd FLOOR


M
W
DARK RM
STOR
OFFICE
WORKSHOP
LABORATORIES
DRAFTING
CLASSRM
LABS
STOR
CLASSROOM

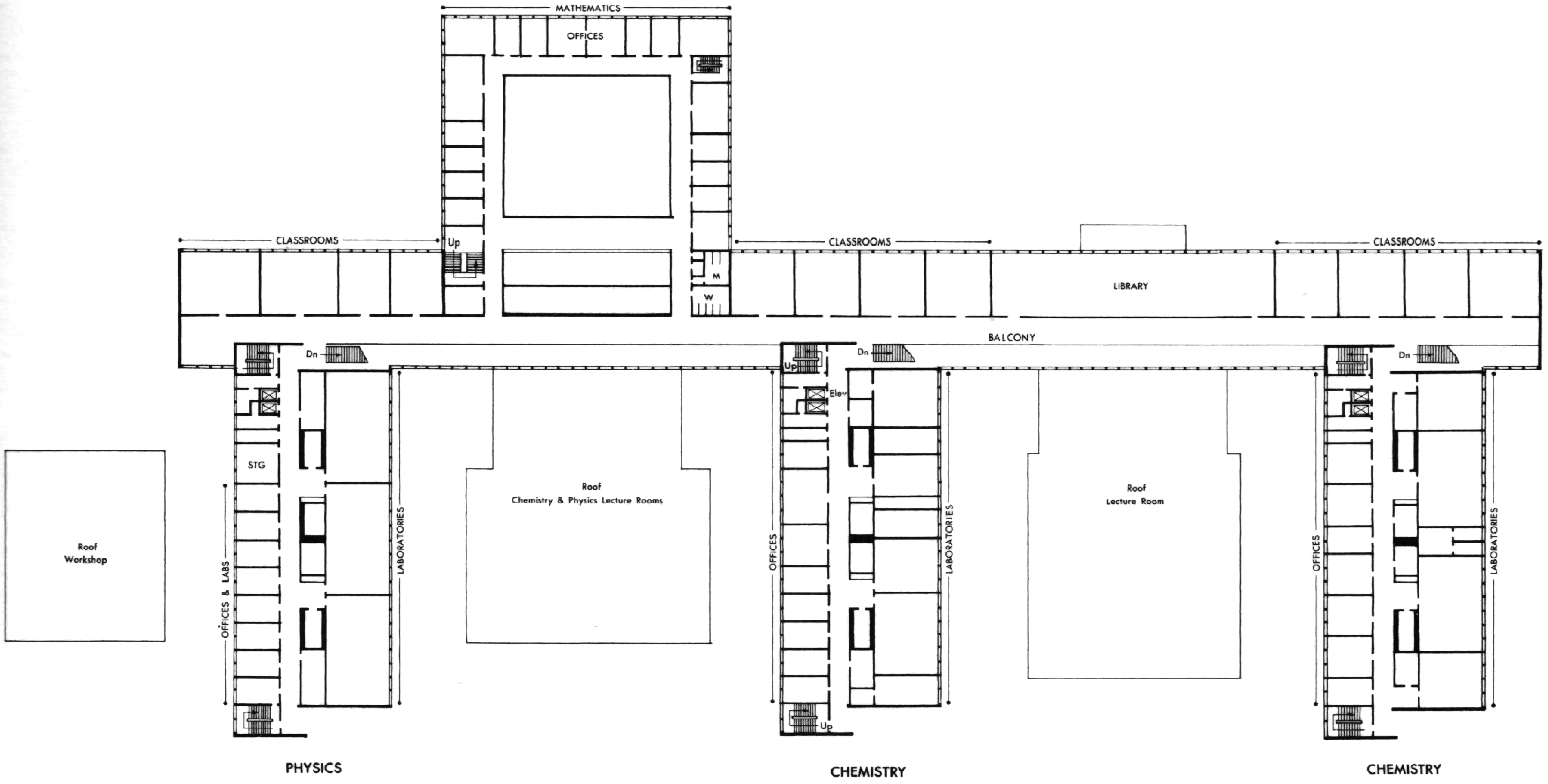
3rd FLOOR


M
W
STOR
LAB
LABS
OFFICE
LABS
DARK ROOMS
STOR
OFFICES
LABORATORIES
COUNTER RM
LAB

4th FLOOR


Up
Dn
M
Elev
W
DARK RM
LAB
OFFICE
LAB
LABORATORIES
DARK RM
OFFICE
Up
CLASS RM
HIGH TENSION RM
OFFICES
LAB
REP
Dn
Up

5th FLOOR


MATHEMATICS
OFFICES
CLASSROOMS
Up
CLASSROOMS
CLASSROOMS
M
W
LIBRARY
BALCONY
Dn
Dn
Elev
Dn
STG
Roof
Workshop
OFFICES & LABS
LABORATORIES
Roof
Chemistry & Physics Lecture Rooms
OFFICES
LABORATORIES
Roof
Lecture Room
OFFICES
LABORATORIES
Up
PHYSICS
CHEMISTRY
CHEMISTRY

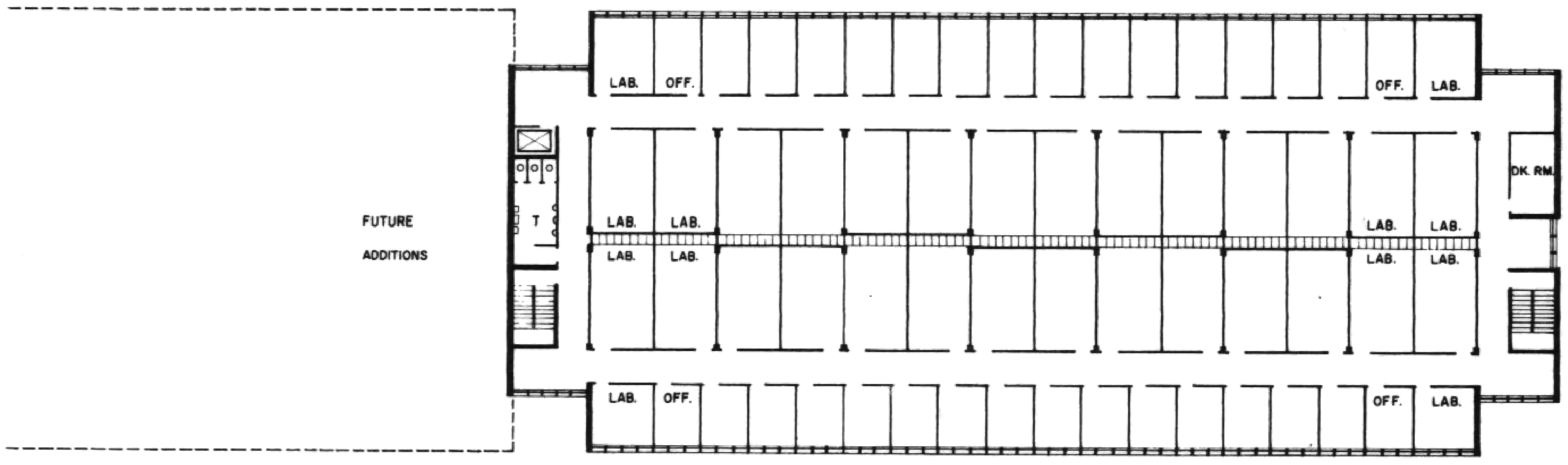
1st FLOOR

32.

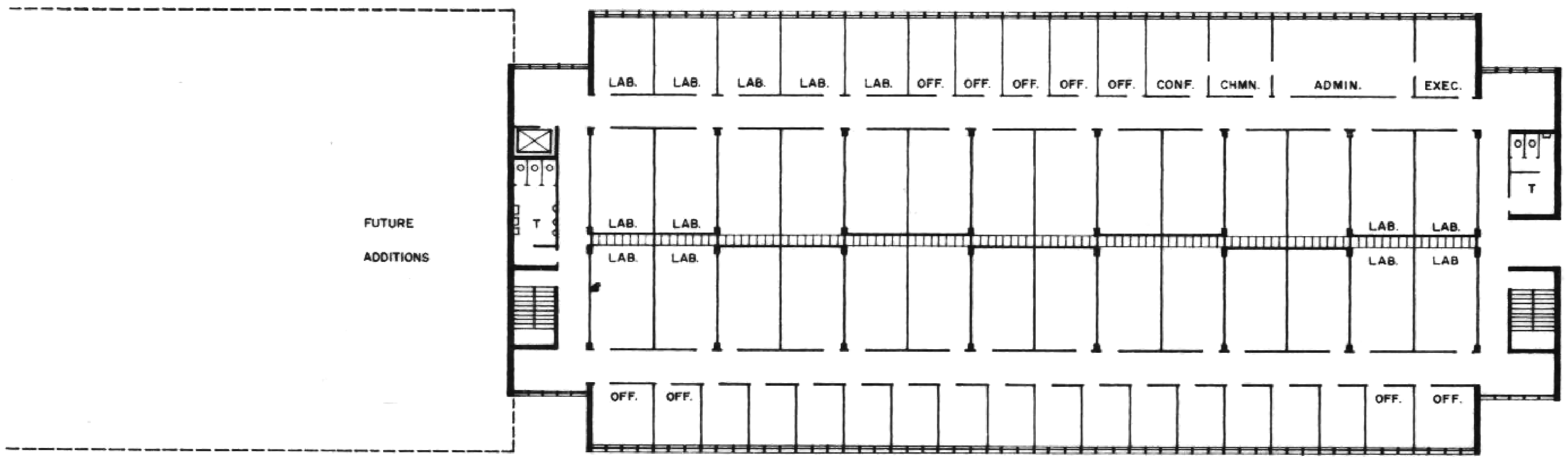
Physics Building
Rutgers University
New Brunswick, New Jersey

Architects:	McDowell-Goldstein Montclair & East Orange, New Jersey
Proposed date of Completion:	July 1962
Gross Area of Building:	58,000 sq. ft.
Total Cost of Building:	$1,555,000*
Air Conditioning:	Dual duct, high velocity, in interior laboratories.

* Includes heating, ventilating, air conditioning, electrical and mechanical services, and laboratory furniture.


LAB.
OFF.
OFF.
LAB.
DK. RM.
FUTURE ADDITIONS
T
LAB.
LAB.
LAB.
LAB.
LAB.
LAB.
LAB.
LAB.
LAB.
OFF.
OFF.
LAB.

SECOND FLOOR PLAN


LAB.
LAB.
LAB.
LAB.
LAB.
OFF.
OFF.
OFF.
OFF.
OFF.
CONF.
CHMN.
ADMIN.
EXEC.
FUTURE ADDITIONS
T
T
LAB.
LAB.
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LAB.
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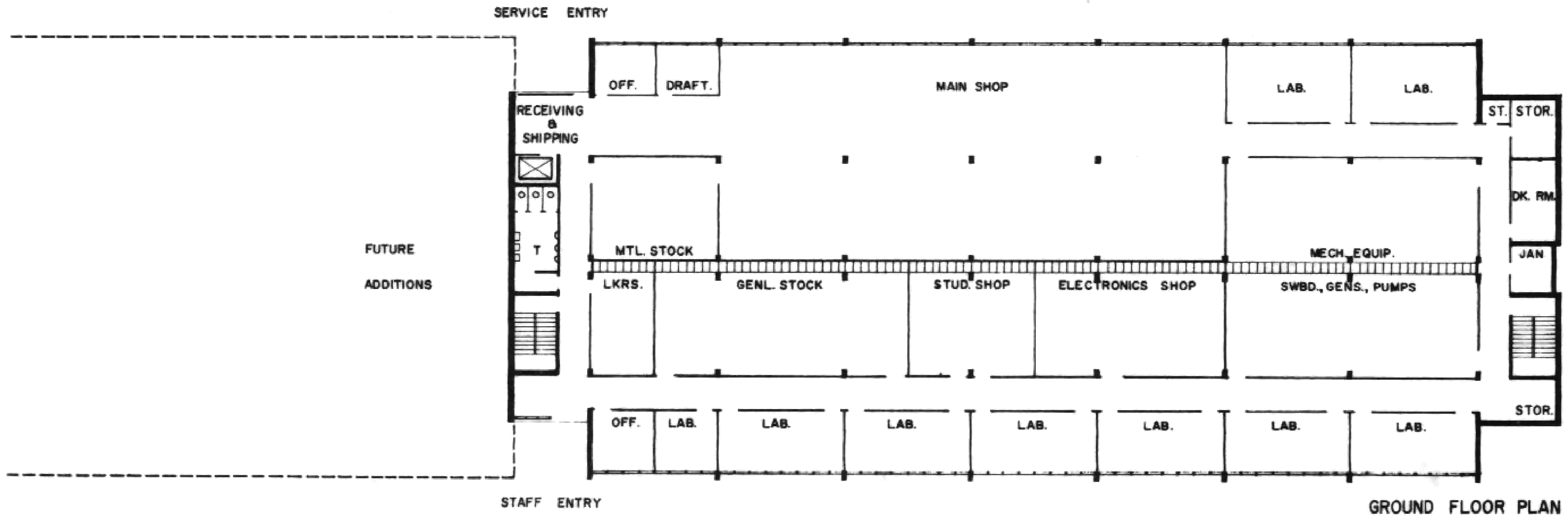
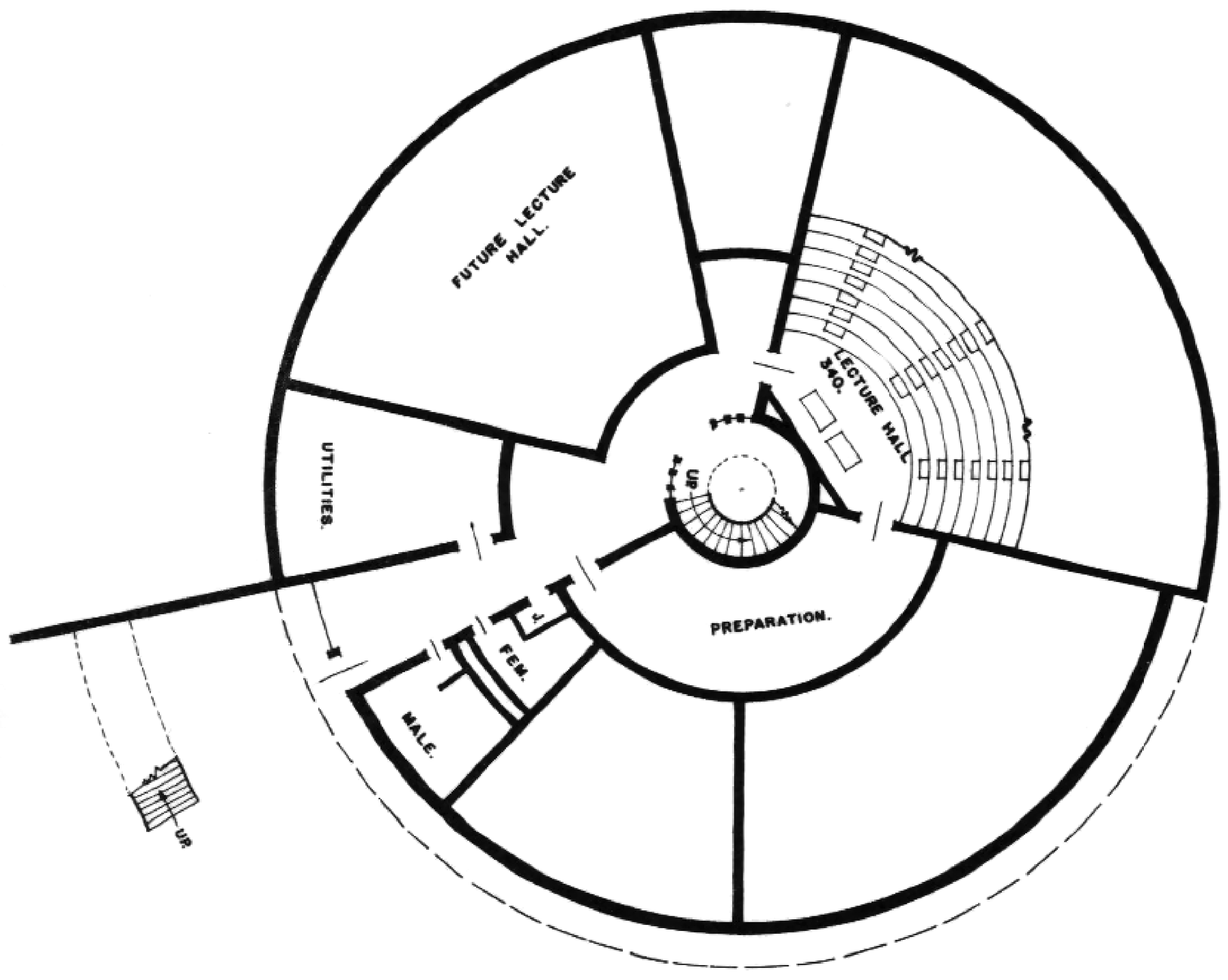
LAB.
LAB.
LAB.
OFF.
OFF.
OFF.
OFF.

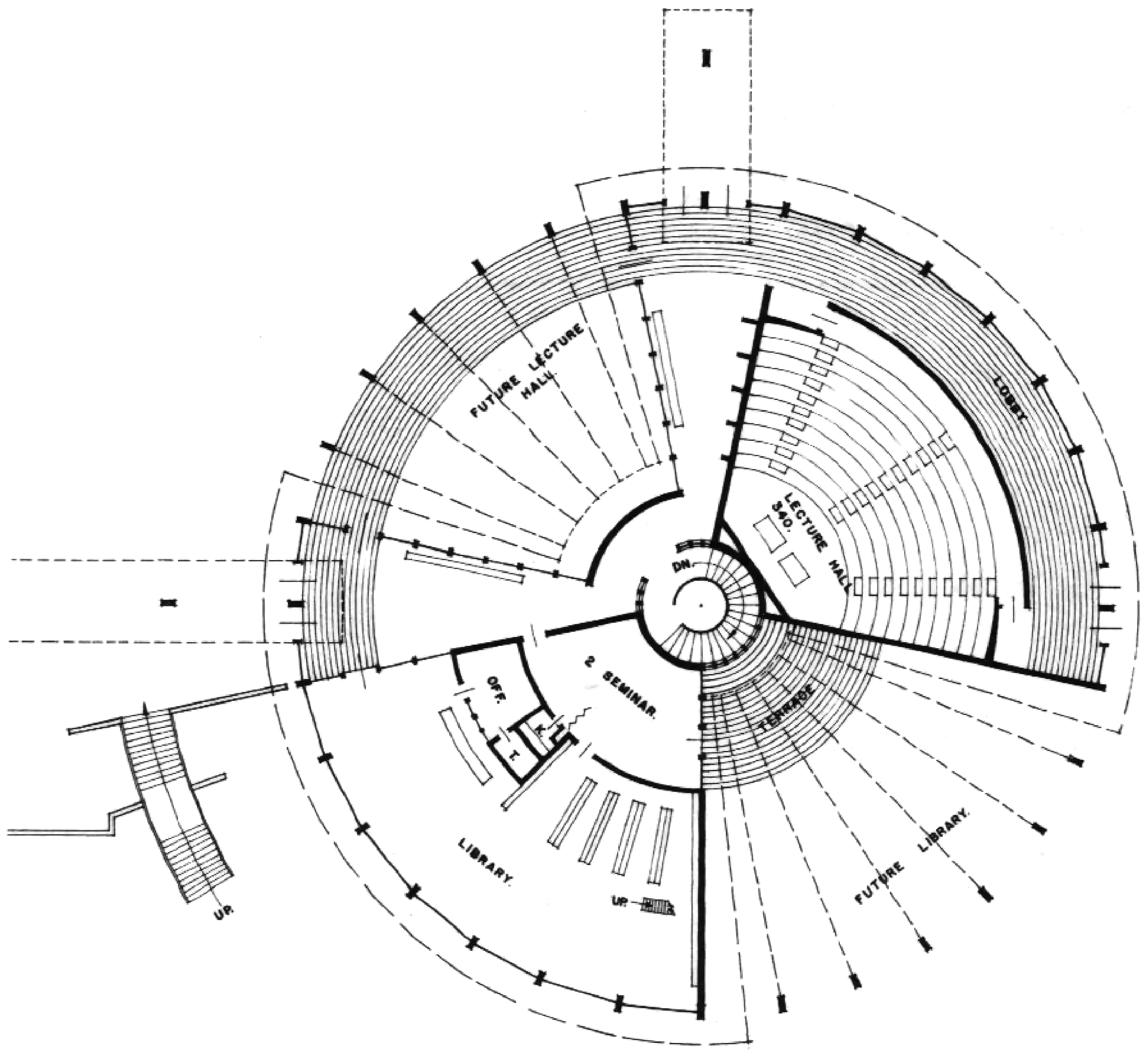
FIRST FLOOR PLAN


SERVICE ENTRY
OFF.
DRAFT.
MAIN SHOP
LAB.
LAB.
ST.
STOR.
RECEIVING & SHIPPING
DK. RM.
JAN
FUTURE ADDITIONS
T
MTL. STOCK
MECH. EQUIP.
LKRS.
GENL. STOCK
STUD. SHOP
ELECTRONICS SHOP
SWBD., GENS., PUMPS
STOR.
OFF.
LAB.
LAB.
LAB.
LAB.
LAB.
LAB.
LAB.
STAFF ENTRY

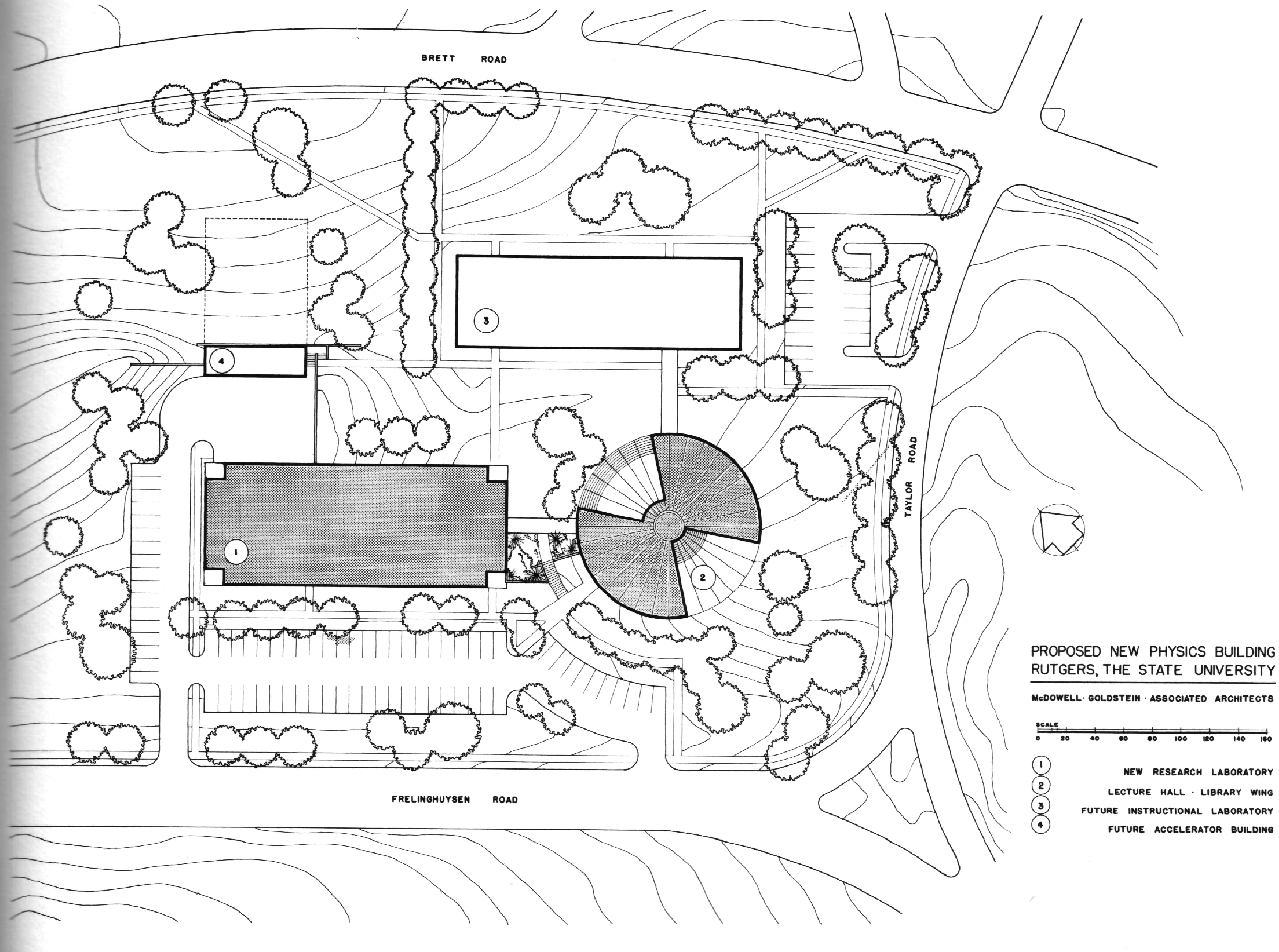
GROUND FLOOR PLAN


FUTURE LECTURE HALL.
LECTURE HALL 340.
UTILITIES.
UP.
PREPARATION.
J.
FEM.
MALE.
UP.

BASEMENT PLAN.


I
FUTURE LECTURE HALL.
LOBBY
LECTURE HALL 340.
DN.
I
OFF.
2 SEMINAR.
K.
T.
TERRACE
LIBRARY.
UP.
FUTURE LIBRARY.
UP.

FIRST FLOOR PLAN.


BRETT ROAD
3
4
1
2
TAYLOR ROAD
FRELINGHUYSEN ROAD
SCALE
0
20
40
60
80
100
120
140
160

PROPOSED NEW PHYSICS BUILDING
RUTGERS, THE STATE UNIVERSITY

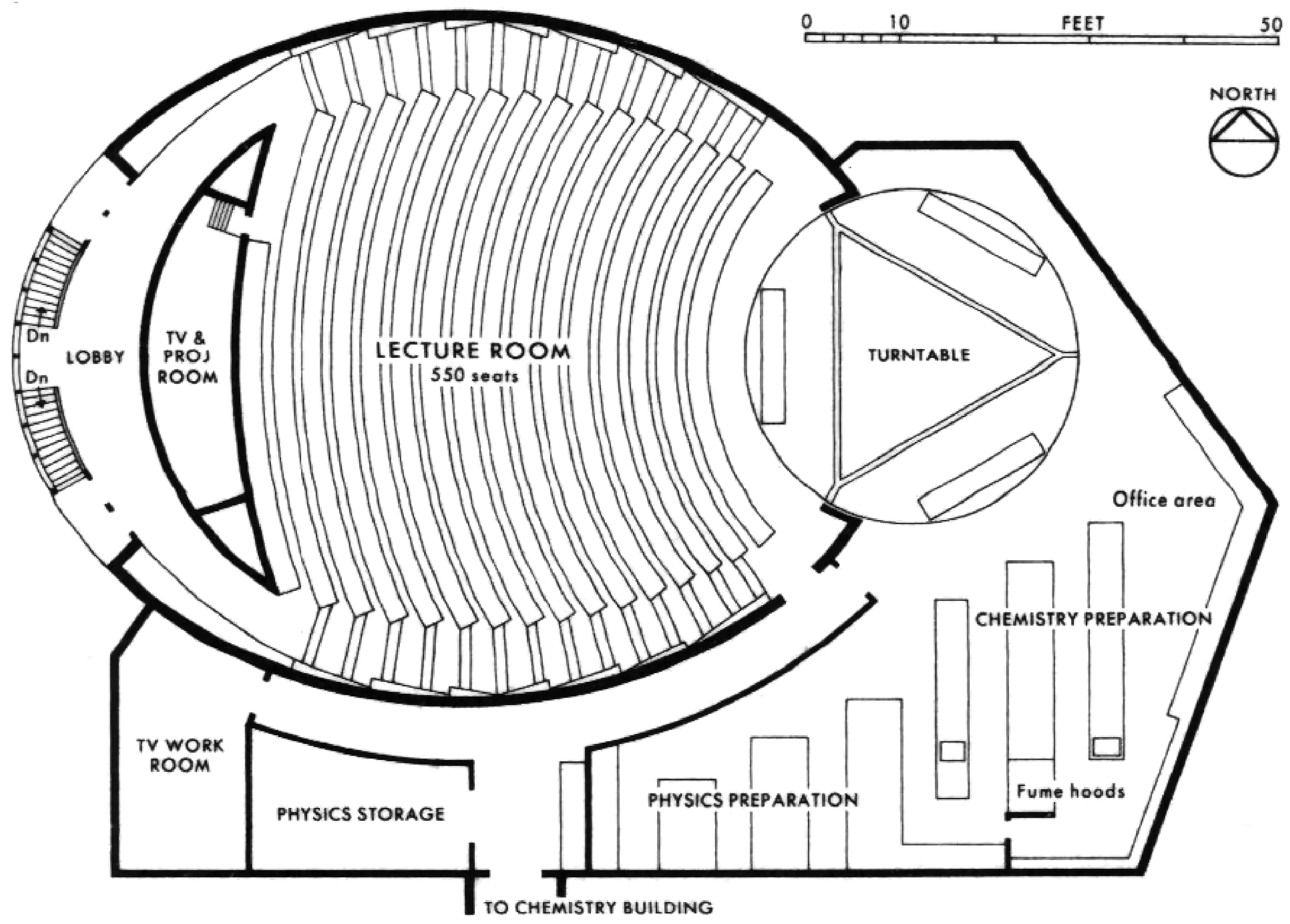
McDOWELL · GOLDSTEIN · ASSOCIATED ARCHITECTS

① NEW RESEARCH LABORATORY
② LECTURE HALL · LIBRARY WING
③ FUTURE INSTRUCTIONAL LABORATORY
④ FUTURE ACCELERATOR BUILDING

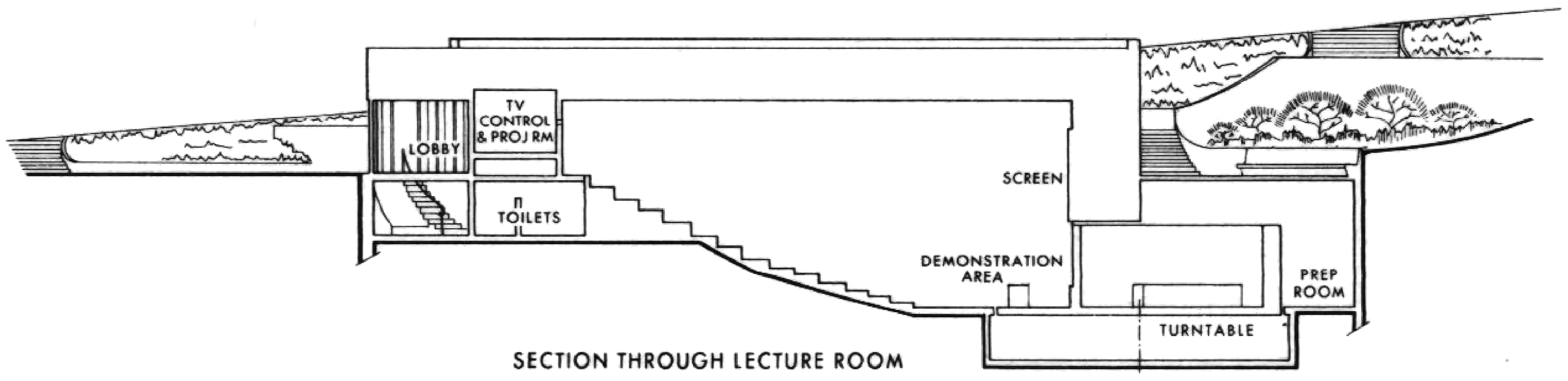
33.

Proposed Physical Sciences Lecture Hall
University of California
Berkeley, California

Architects:	Anshen & Allen San Francisco, California
Proposed Completion:	1962
Gross Area of Building:	12,700 sq. ft.
Total Cost of Building:	Not available
Air Conditioning:	None


0
10
FEET
50
NORTH
LOBBY
Dn
Dn
TV & PROJ ROOM
LECTURE ROOM
550 seats
TURNTABLE
Office area
CHEMISTRY PREPARATION
Fume hoods
PHYSICS PREPARATION
TV WORK ROOM
PHYSICS STORAGE
TO CHEMISTRY BUILDING

LECTURE ROOM AND BASEMENT PLAN


TV CONTROL & PROJ RM
LOBBY
TOILETS
SCREEN
DEMONSTRATION AREA
PREP ROOM
TURNTABLE

SECTION THROUGH LECTURE ROOM

5. The Lecture Room

INTRODUCTION

Most beginning physics students make their initial contact with physics in the lecture room—and often their only contact with their principal physics instructor. The room, therefore, takes on a special quality as the fountainhead of physics and should have characteristics that will make it most effective for transmitting knowledge and inspiring study.

Floor plans and interior photographs of a number of lecture rooms are distributed throughout this chapter to illustrate general planning and to show details of design. The lecture rooms chosen have been selected, not because they are necessarily to be recommended as ideal solutions, but because they illustrate certain design features. What is a satisfactory solution at one institution will not necessarily meet the needs at another.

Where the floor plans and photographs for a particular lecture room contribute something to each other, they will be presented together, even though the photographs illustrate features described in a different section of the chapter. We believe that the advantage gained overshadows the inconvenience of having to refer to figures that may be several pages removed from the text.

GENERAL PHYSICAL CHARACTERISTICS OF LECTURE ROOMS

Location

Because of the special physical requirements of a physics lecture room, its location must be given special consideration in the general design of a new building. The most versatile and apparently most effective lecture facilities result when the lecture room is designed to fit the special instructional needs of the institution and to be well-coordinated with the building it is to serve. The problem of design is fairly simple if the room is required to seat no more than about 60 students. Such a room can readily be accommodated within the framework of any science building. However, when a larger room is required, and especially when the room must also serve for public meetings, the problem is considerably more complicated. Most of our comments will be directed toward the latter problem.

Since a lecture room usually serves a large number of people, it should be so located that there will be a minimum of confusion caused by student traffic through corridors and on stairways when classes change. This is best accomplished if the lecture room is

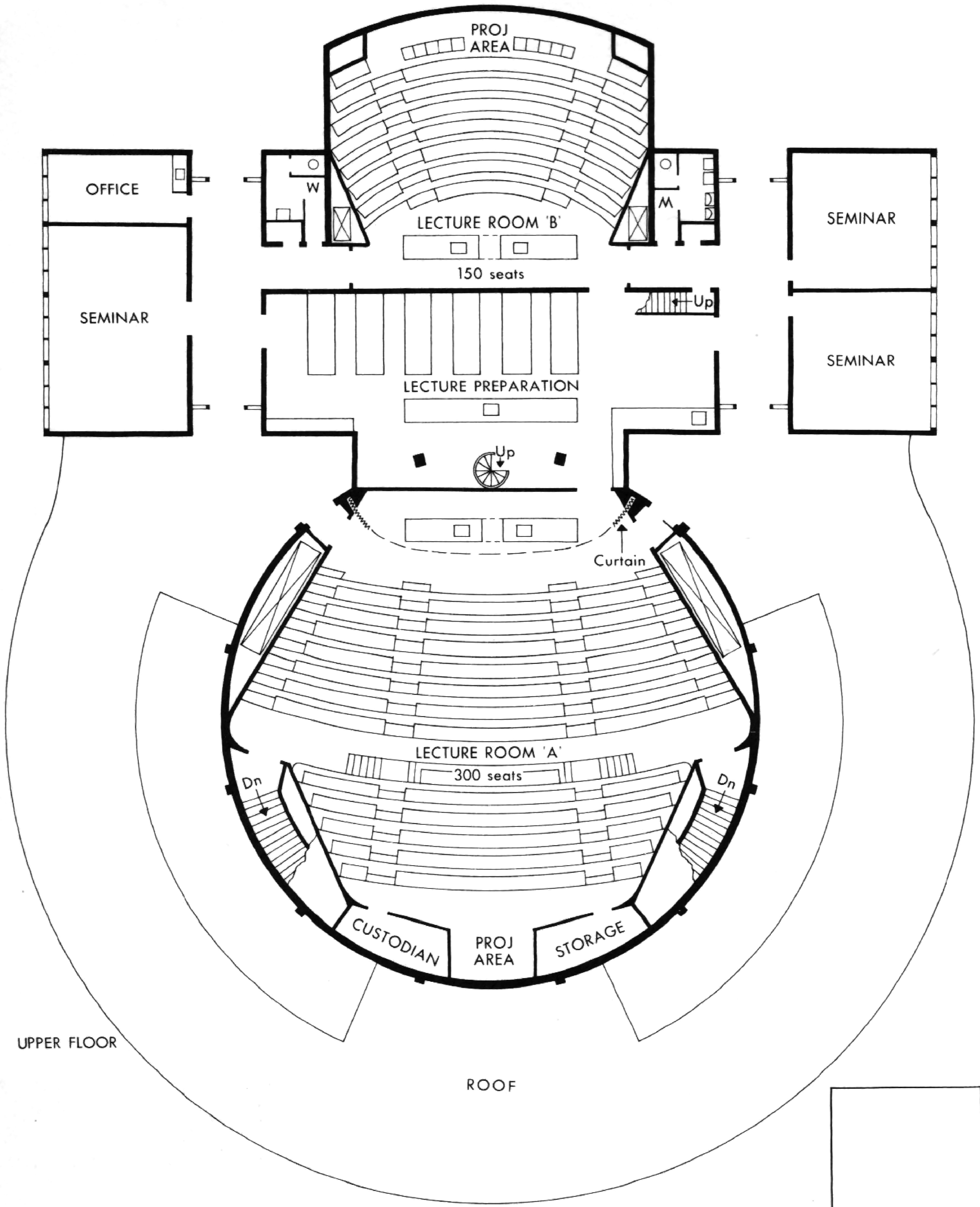
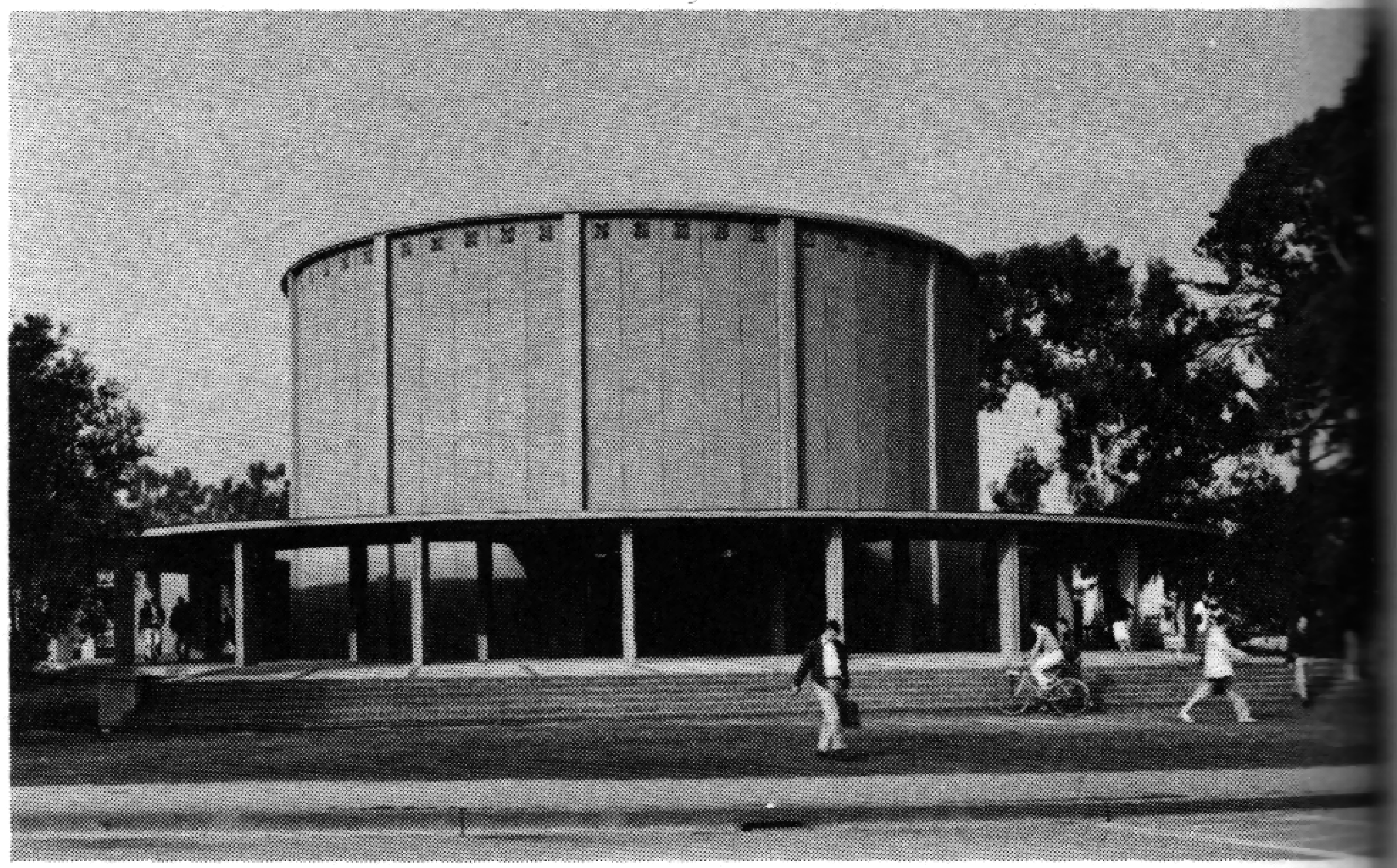
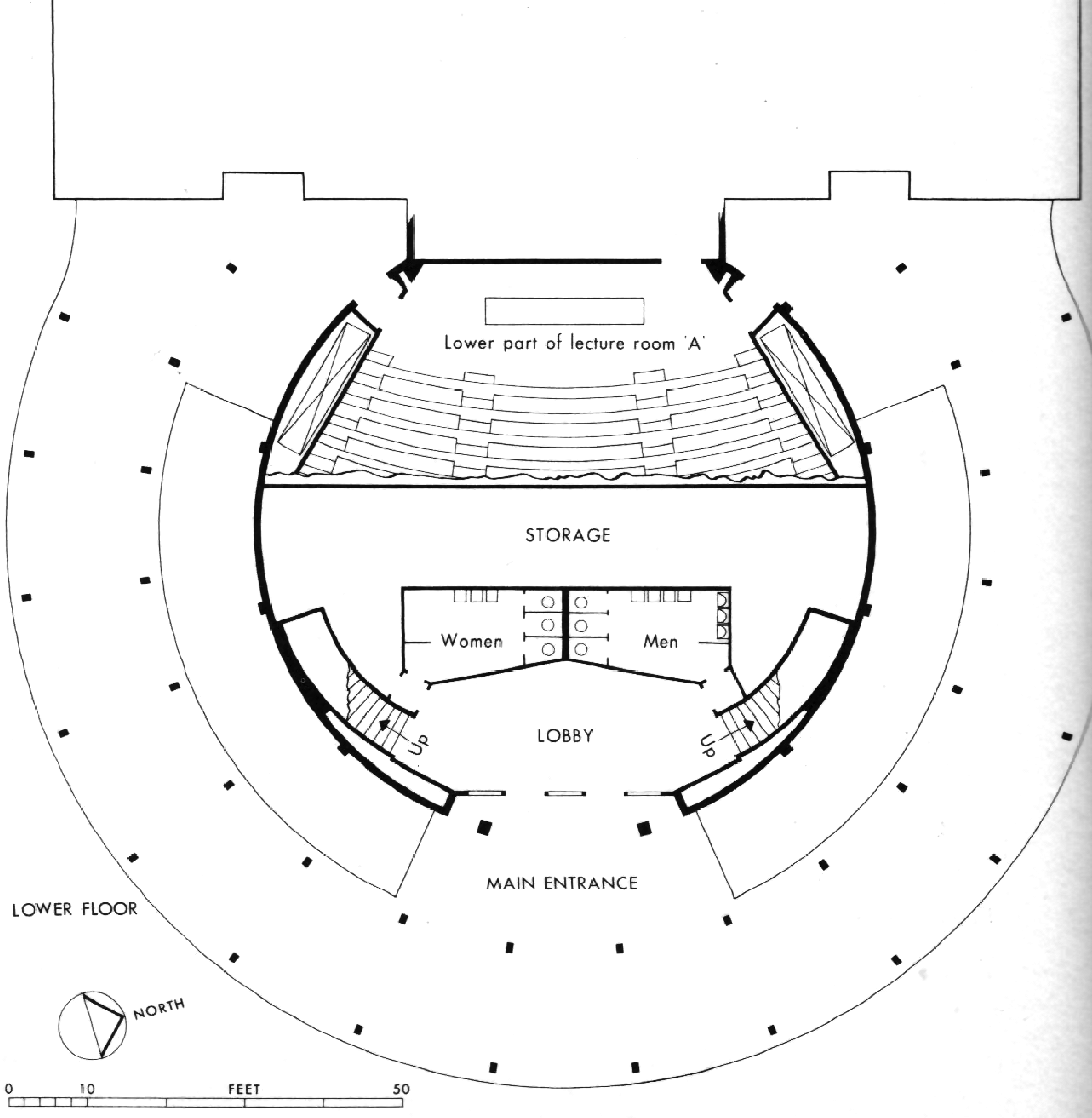
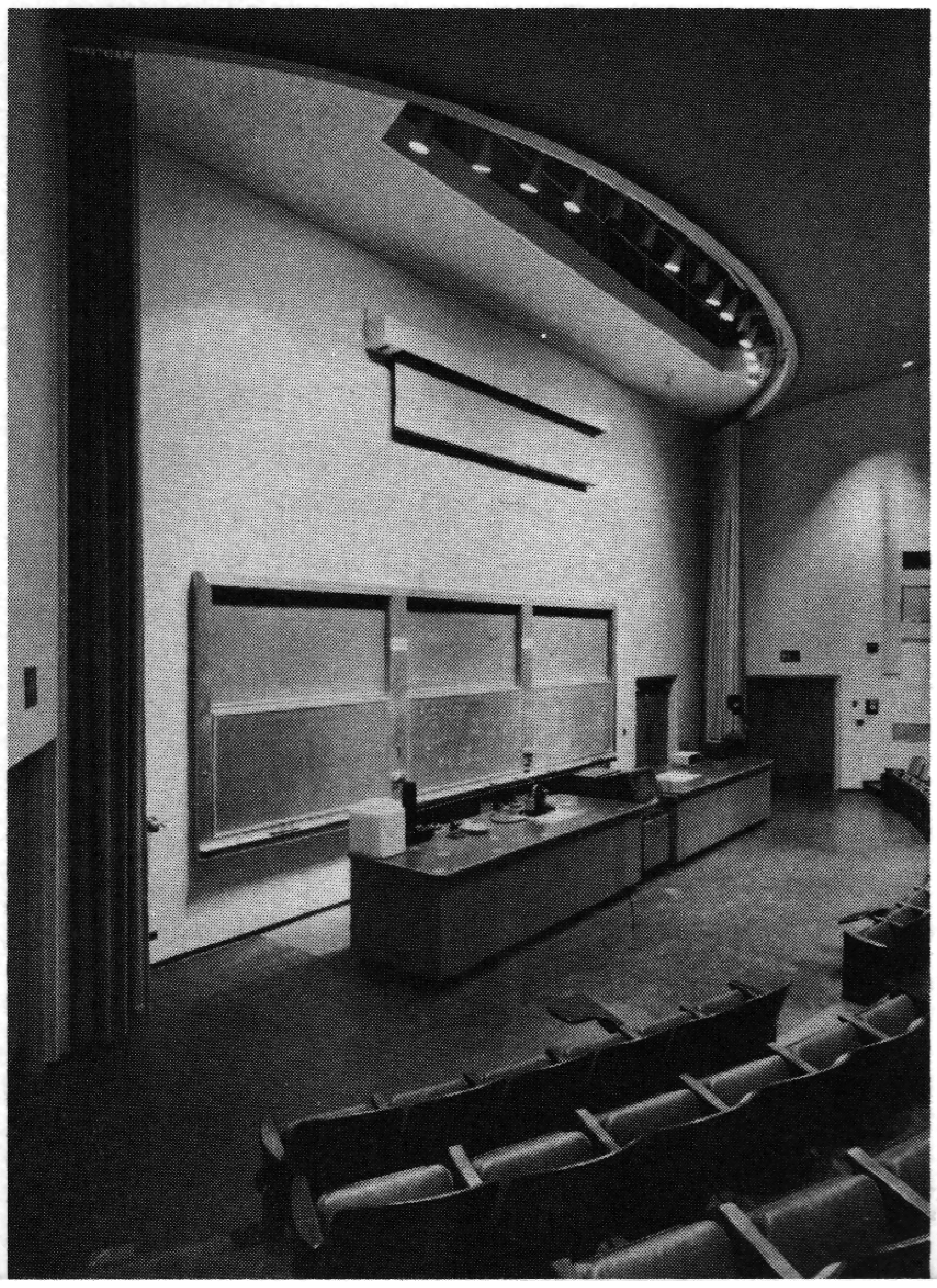

PROJ AREA
OFFICE
W
W
LECTURE ROOM 'B'
150 seats
SEMINAR
SEMINAR
Up
SEMINAR
LECTURE PREPARATION
Up
Curtain
LECTURE ROOM 'A'
300 seats
Dn
Dn
CUSTODIAN
PROJ AREA
STORAGE
UPPER FLOOR
ROOF

Figure 1. Physics Lecture Hall Building, Stanford University. It was completed in August, 1959 at a total cost of $590,000 (including heating, ventilating, electrical and mechanical services, and furniture). Gross area is 16,000 square feet. Gardner A. Dailey and Associates, Architects, San Francisco.

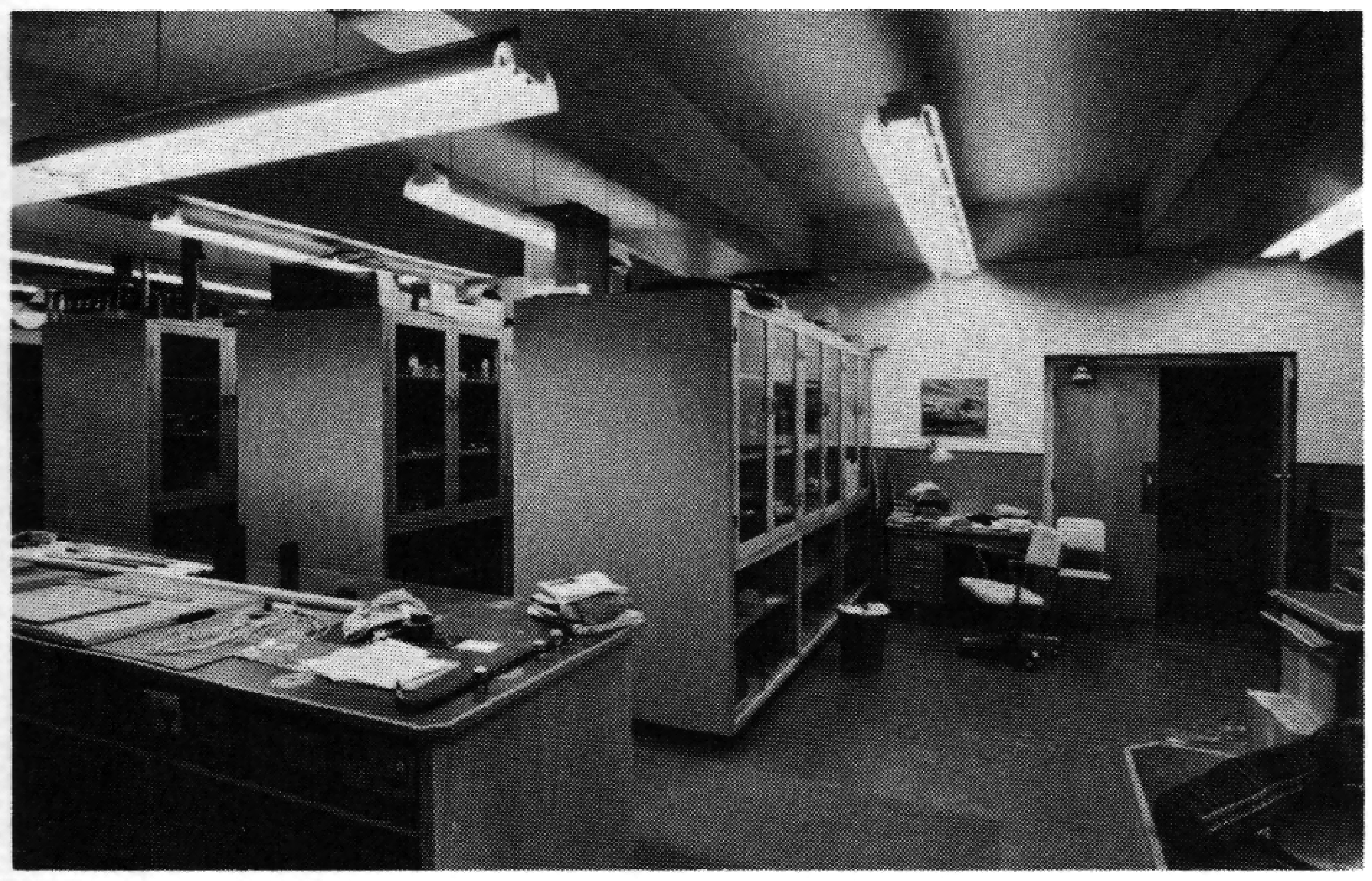



Lower part of lecture room 'A'
STORAGE
Women
Men
Up
Up
LOBBY
MAIN ENTRANCE
LOWER FLOOR
NORTH
0
10
FEET
50

Front view in large lecture room. Note floodlights and catwalk in opening in ceiling.



Common storeroom for the two lecture rooms. The preparation table (left foreground) is a duplicate of tables installed in the lecture rooms.

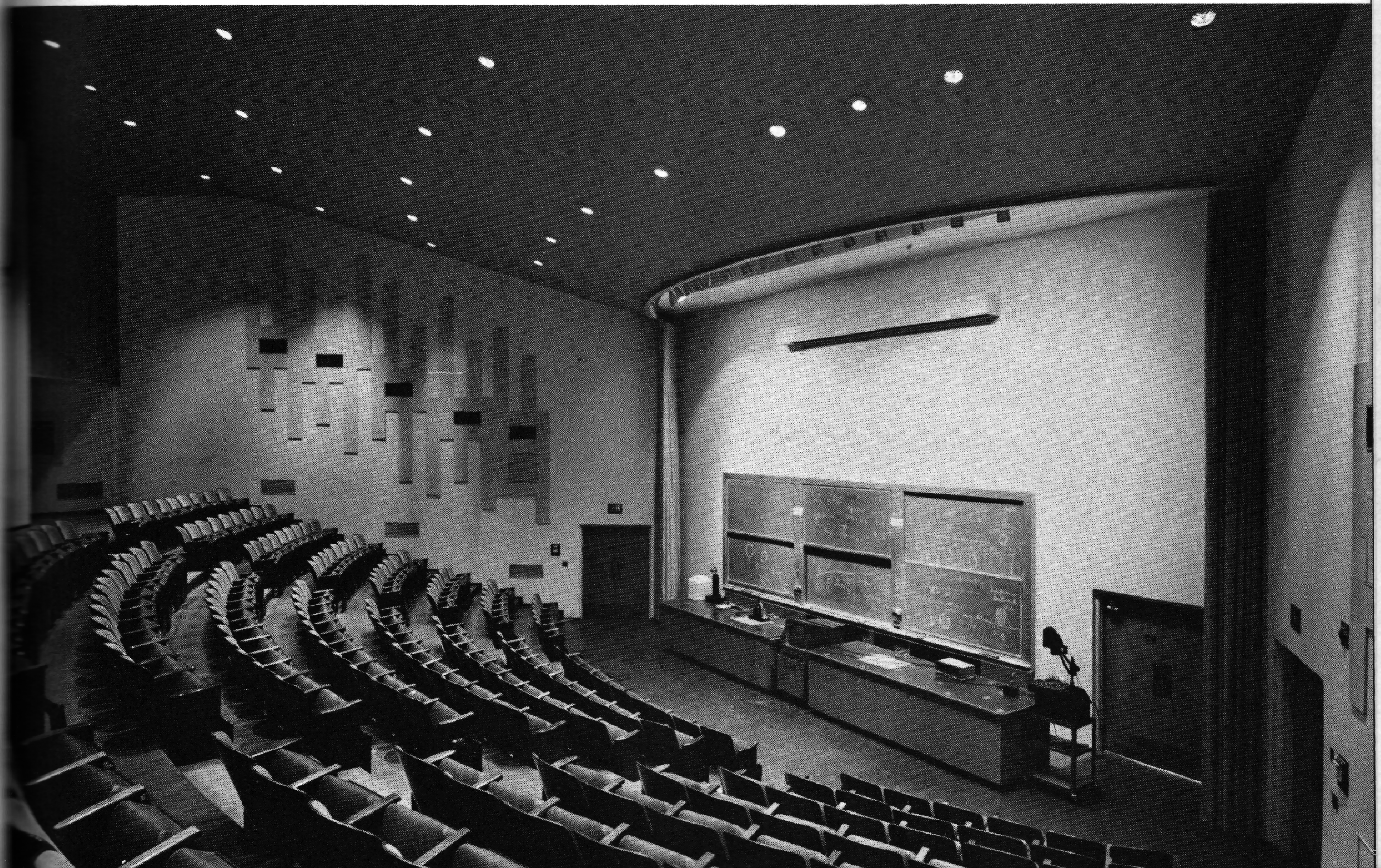


located either in a wing of the building or in a separate lecture hall building so that it has its own entrance from out-of-doors.

The new Lecture Hall Building at Stanford University (Figure 1) achieves this objective. It houses two lecture rooms, a common apparatus storeroom and three classrooms. One of the lecture rooms seats 150, the other 300. A number of the features which appear in the photographs of Figure 1 will be discussed in subsequent sections.

The physics lecture room at Pomona College is located in a wing of the physics building (Figure 11, Chapter 4). Its main entrance is also from out-of-doors. However, it is conveniently connected to the physics building by means of a covered arcade at the main floor level and by way of the

View of large lecture room. Note screen which can be drawn to enclose the lecture table.



apparatus storeroom at the ground floor level, as shown in Figure 2.

Student traffic through corridors can also be kept to a minimum if the lecture room opens onto a lobby which in turn opens directly onto the campus. The lecture room in the duPont Physical Science Building at Swarthmore College (Figure 25 in Chapter 4) is located in one wing of the building as shown in Figure 3. Its lobby not only opens directly onto the campus but also provides immediate access to the corridors of the science building.

In general it is not desirable to locate a large lecture room in the middle of a large building—particularly if students must pass some distance through corridors to reach exits. However, if the lecture hall opens onto a sufficiently large lobby, student traffic may be accommodated satisfactorily. This is the plan adopted in the massive Eyring Science Center at Brigham Young University which houses the departments of physics, chemistry, and geology. Each department has its own group of three lecture rooms and all three groups are located in the heart of the building. The largest of the three rooms in each group opens up onto a large common lobby which is immediately adjacent to the main entrance to the building as shown in Figure 17 of Chapter 4.

Another plan in which three lecture rooms and a common apparatus storeroom were successfully incorporated in the heart of a building is that for the physics building at the University of Minnesota. The large 500-seat lecture room opens onto the main lobby and the other two open onto corridors at points where there are other exits from the building.[1]

Four lecture halls and a common apparatus storeroom are located in the LeConte Addition to the Physics Building at the University of California in Berkeley and, as shown in Figure 1 of Chapter 4, the plan adopted provides each lecture room with easy egress to the campus without appreciable use of the corridors.

When a lecture room is to be used occa-

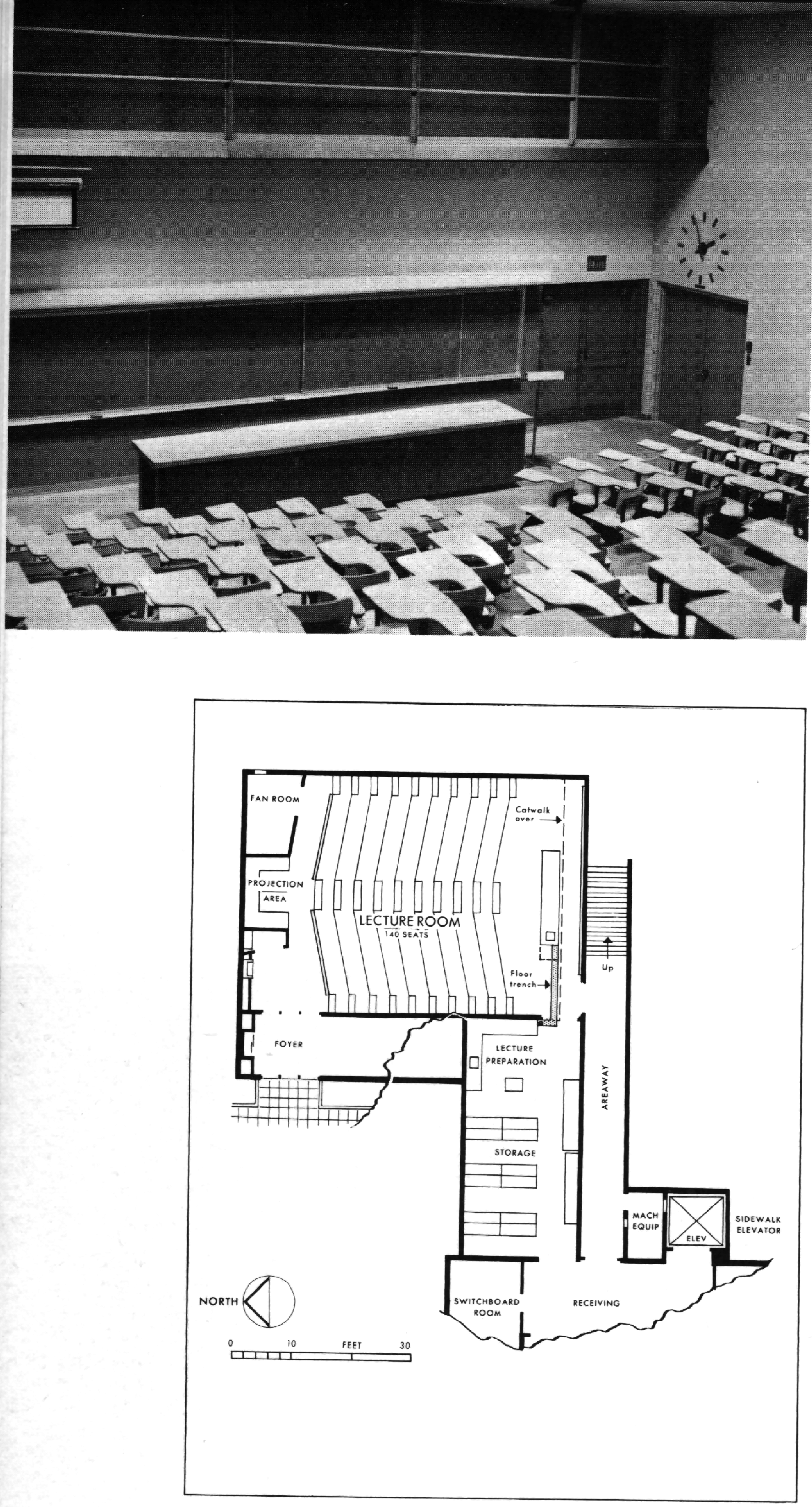


Figure 2. Lecture room, Millikan Laboratory of Physics, Pomona College (Chapter 4, Figure 11). Note catwalk and movable chalkboards which roll sideways.

sionally for public meetings it should be possible to shut it off from the rest of the building. This can most readily be done if the lecture room is at one end of the building or in a separate wing, and also if it is on the ground floor.

A large lecture room should not be located on an upper floor. This advice may be difficult to follow in a building designed to house several departments each on a different floor. Each department may want its own

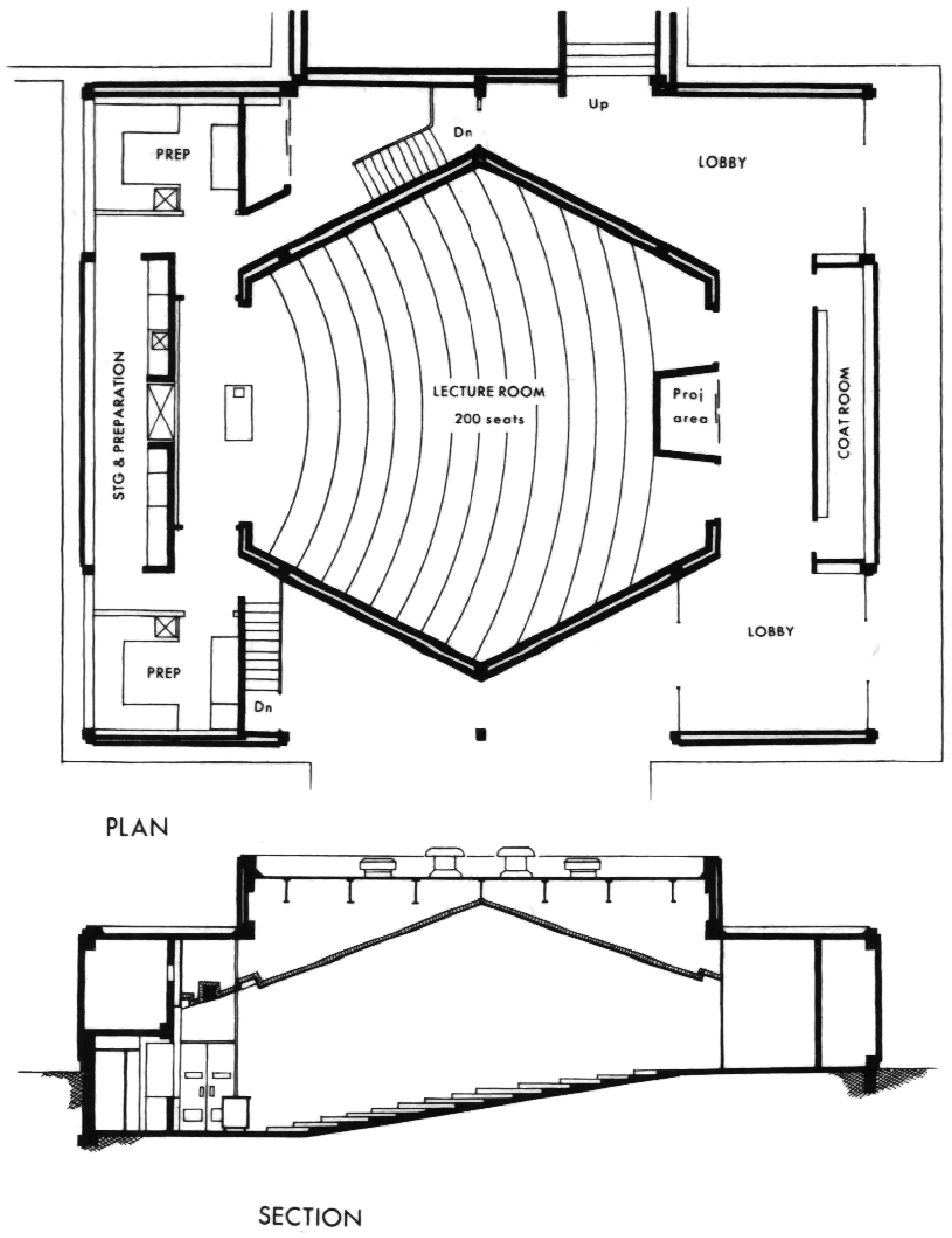
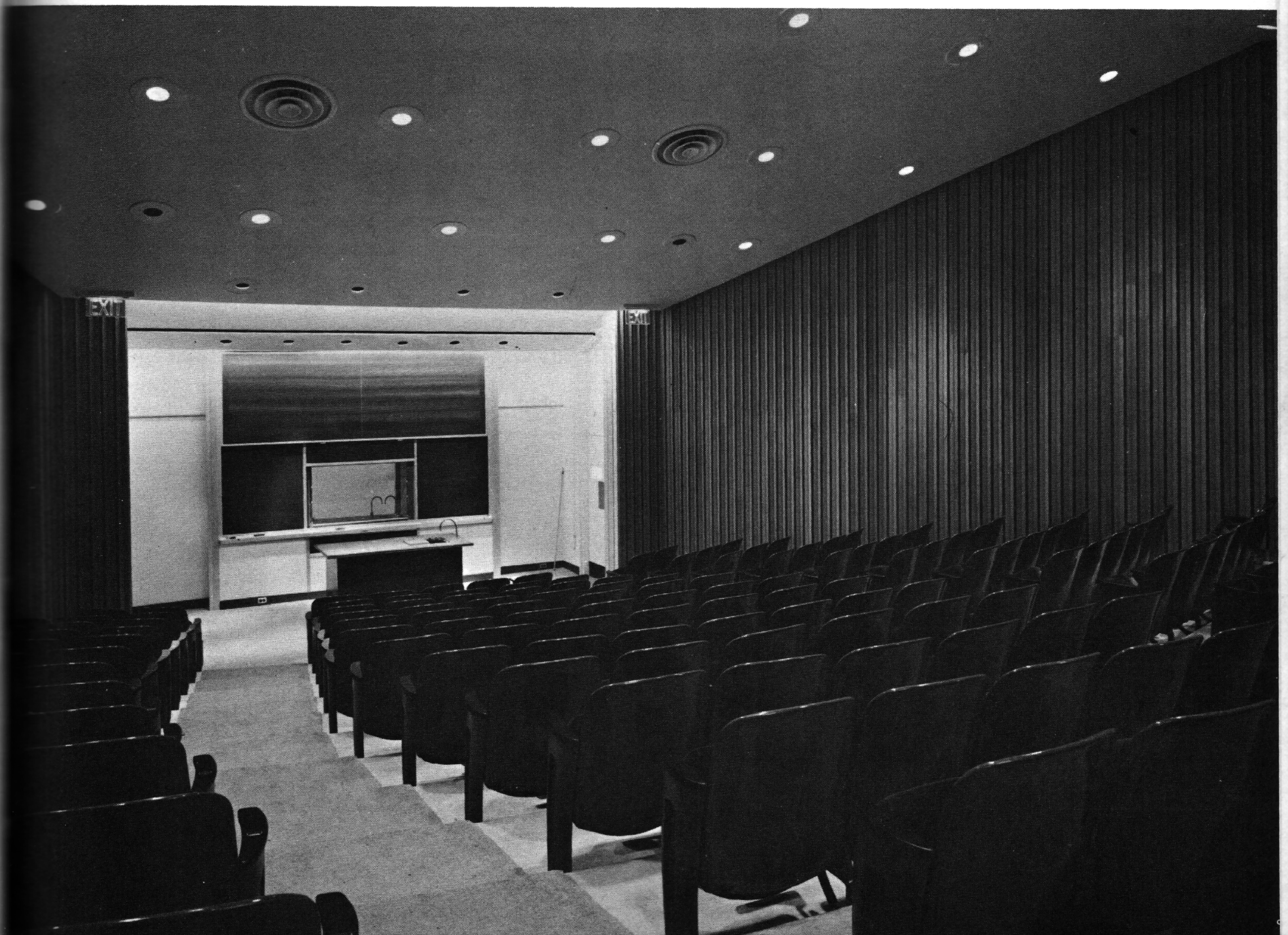

Up
Dn
LOBBY
PREP
STG & PREPARATION
LECTURE ROOM
200 seats
Proj
area
COAT ROOM
LOBBY
PREP
Dn
PLAN
SECTION

Figure 3. Lecture room, duPont Science Building, Swarthmore College (Chapter 4, Figure 25). Center chalkboard is raised to expose fume hood.



lecture room. If possible a plan should be developed which will not place all lecture rooms adjacent to the same stairs. At one institution where three lecture rooms are stacked one above the other we have had reports of considerable confusion when classes change.

In general, it cannot be stressed too heavily that in planning a new building, careful studies of class schedules should be made to predict the pattern that student traffic will probably take for each of several possible locations of the lecture room. Moreover, the location of other buildings on the campus must be taken into consideration, for this will determine which entrance to the new building will be most frequently used by students.

In addition to traffic considerations, the size and shape of a lecture room enter into the decision as to its best location. In particular, when a large auditorium is desired, the architect is given much greater freedom if he can consider housing it in a special auditorium wing.

Size of Lecture Room

A number of factors must be considered in determining the desirable size of a lecture room. Foremost is the opinion of the institution and the physics staff as to the maximum

Table I. Report on Lecture Room Sizes in Physics

(Data obtained from a card survey conducted by the American Association of Physics Teachers Committee on The Design of Physics Buildings in late 1957. Information is from 430 physics departments offering a major in physics.)

1. Number of lecture rooms distributed according to seating capacity, reported in use by responding departments.

Seating capacity	0–50	51–100	101–200	201–300	301–400	over 400
Number rooms	318	245	151	39	18	5

Total rooms: 776

2. Number of departments reporting at least one lecture room of stated seating capacity, distributed according to seating capacity.

Seating capacity	0–50	51–100	101–200	201–300	301–400	over 400
Number departments	287	232	138	39	16	5

3. Number of lecture rooms distributed according to seating capacity and according to number of lecture rooms used within the department.

Seating Capacity	0–50	51–100	101–200	201–300	301–400	over 400
Rooms within department						
1	72	60	32	9	3	0
2	93	78	51	13	8	3
3	140	102	57	17	3	1
4	7	2	7	0	3	1
5	4	1	4	0	1	0
6	2	2	0	0	0	0

Total rooms: 776

number of students who can be taught effectively in a single lecture section. We found this to range upward from thirty, with some physics departments apparently willing to accept as many as 400 or 500 students in each section. The latter, however, were departments which already had or could foresee such large enrollments that the problem of finding teaching staff was becoming acute.

For various reasons lecture rooms are frequently designed to have a greater seating capacity than optimum teaching conditions require. Sometimes this extra capacity is useful; if twice the number of seats required for lectures is available, students can occupy alternate seats for examinations. Furthermore, a larger room is more versatile for general use. It can be used by other departments which lecture to large classes and for large meetings or special assemblies.

However, one department chairman had this to say about the question: "Strange as it may seem, we have found the largest lecture room, seating 500, a serious handicap at times." He described the difficulties which arise because the room-scheduling officers either deny the physics department the use of their specially equipped large lecture room in order to schedule other large classes there, or insist that the room be used to capacity by the physics department even though his staff wishes to hold class size down.

Table I gives an idea of the sizes of physics lecture rooms in colleges and universities in the United States. The information was obtained as the result of a card survey conducted by the AAPT Committee on the Design of Physics Buildings in the fall of 1957. The questionnaire was sent to the 540 physics departments which offer a major in physics and 430 replies were received. Apparently most physics lecture rooms seat less than 100 students and very few seat more than 400.

The problems of seeing and hearing increase with the size of the lecture room. Special measures must be taken to solve both problems. The floor must be sloped (this is, of course, necessary even for small lecture rooms), and large lecture rooms must be specially shaped. Furthermore, for large lecture rooms apparatus for lecture demonstrations must be made larger and chalkboards become less effective as teaching tools. Special optical projection techniques must be resorted to. As pointed out in the report of the Wesleyan Conference on Lecture Demonstrations in Physics the use of large apparatus requires a larger apparatus storage room.[2] A fuzzy point of diminishing returns is eventually reached as the size of a lecture room increases.

Visibility

How visible is chalkboard writing? The large "E" on the Snellen chart is 3½ inches high and can be recognized by the "average" eye at 200 feet. This would suggest that 1-inch letters on a chalkboard should be visible to a student at 50 feet. However, this figure is for seeing under ideal conditions, and with concentration. Furthermore, not all students have good vision, and special concentration should not be required to insure correct recognition of symbols. Therefore, most instructors tend to write much larger—probably about twice as large. Two-inch letters on lines 3 inches apart would allow only 14 lines to be written on a chalkboard 3½ feet high, and only seven or eight printed words per 4-foot line. Not only must words be legible, but the separate parts of line drawings and associated symbols must also be clearly identifiable. Such considerations not only enable one to estimate the amount of chalkboard area required for a proposed lecture room but also the extent to which the chalkboard must be supplemented by other methods of instruction in an existing lecture room.

Some persons find that it is easier to write large when they use the oversize ⅝-inch-diameter chalk. Letters are bolder, lines are broader, and consequently symbols are easier to identify at a distance.

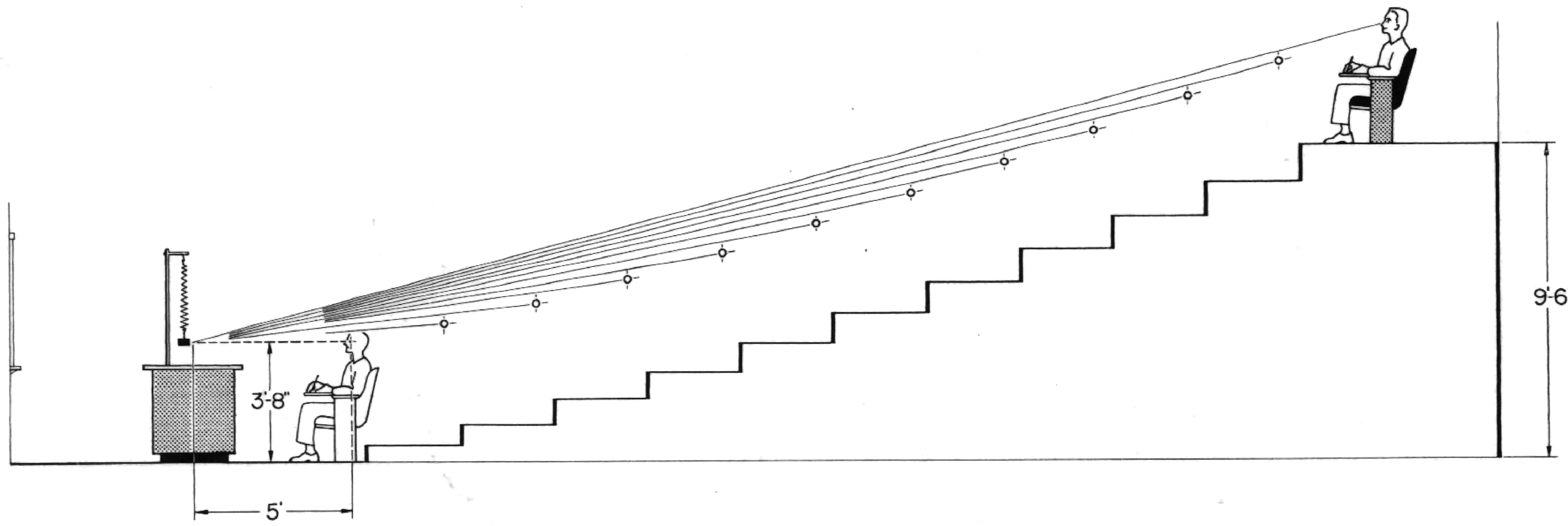
Slope of Lecture Room

In the physics lecture rooms we have visited, the slope varies from zero up to that of Burr Hall A at Harvard University where the angle is 34° and seats rise by 22 inches between successive rows, 33 inches apart.[3] Some reasonable amount of slope is desired so that students can easily see lecture demonstrations most of which are carried out at table top level. But just what slope is "reasonable" appears to be primarily a matter of personal choice. Some instructors want students to be able to see demonstrations carried out on the floor in front of the lecture table; this requires either that the slope be quite large or that the seats be set back a considerable distance from the lecture table. Others point out that much of the demonstration apparatus that is available commercially is designed to be viewed most effectively from a horizontal direction. If the slope is too large, the student's line of sight is not right and specially designed apparatus is required.

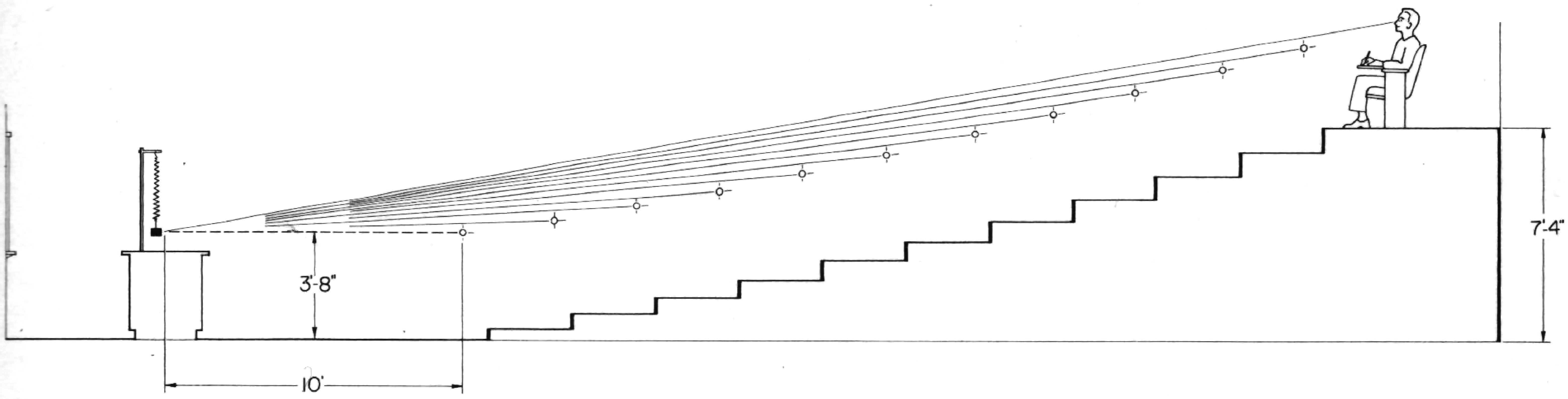
Again, there are those who point out that the instructor does not spend all his time performing demonstrations. Much of the time he is talking, and effective instruction requires that he be able to see each student to hold his attention. It is easier to accomplish this if the instructor does not have to lift his eyes too high to see students in the back row. This points to the desirability of a small slope. On the other hand, if the slope is large, the desired effect can be approached if the lecturer is at a greater distance from his audience. The instructors who have occasion to lecture in both Burr Hall A and Burr Hall B at Harvard report that they like the "feel" of B better than A. The slope is about the same in the two rooms (34° in A and 32° in B). However, there is more space between the lecture table and the students in Burr Hall B than in A—space which permits the use of a curved theatrical curtain which when drawn allows apparatus to be set up for a demonstration lecture while the lecture hall is being used for a class not requiring lecture table facilities. The seats in B are about 5 feet farther from the lecture table than in A, and therefore an instructor behind the table need not tilt his head back so far to see the top row.

Several interesting facts are brought out in the sight line drawings of Figure 4. These drawings have been made so that consecutive rows will have the same average sight line clearance. Sight lines are drawn to a point 8 inches above a 36-inch high table so that the line for one row misses the line for the row ahead by the same distances—4 inches in these drawings. (A clearance of somewhat more than 4 inches would be required to see over the top of an "average" adult. Therefore the drawings of Figure 4 assume that, on the average, one's line of sight is a little to one side of the person ahead of him. In making a similar drawing for a proposed lecture room, one might want to allow a larger clearance). The lecture table in drawings (a) and (b) is at the same base level as the first row of seats, whereas in (c) the lecture table is on an 8-inch high platform. In (a) the first row is 5 feet from the center of the lecture table; in (b) and (c) this distance is just over 10 feet. Not only is it clear from the drawings that to maintain constant sight line clearance the slope of the auditorium must increase with distance, but two other facts become evident. The required slope is less when the first row is farther away from the lecture table: in (a) the twelfth row is 9½ feet above the first row; in (b) it is only 7¼ feet. Furthermore, by comparing (b) and (c) one observes that still less slope is required if the lecture table is on a platform: in (c) the twelfth row is only 5½ feet above the first. However, the lecture table should not be so high that its front edge cuts off the view of the apparatus being demonstrated (or the more distant chalkboard) for persons in the front row. The choice of floor slope, moreover, is clearly related to ceiling height, and this is particularly important when the lecture room must be fitted into a building where the ceiling height has been predetermined.

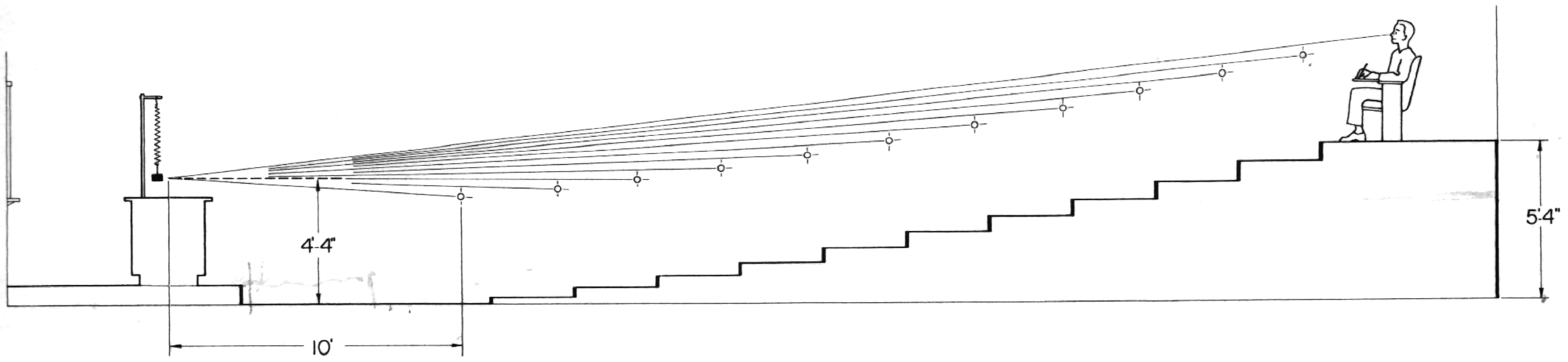
Figure 4. Sight line drawings. Each line misses the row ahead by 4 inches.



First row is 5 feet from object being viewed.



First row is 10 feet from object being viewed.



First row is 10 feet from object; lecture table is placed on 8-inch platform.

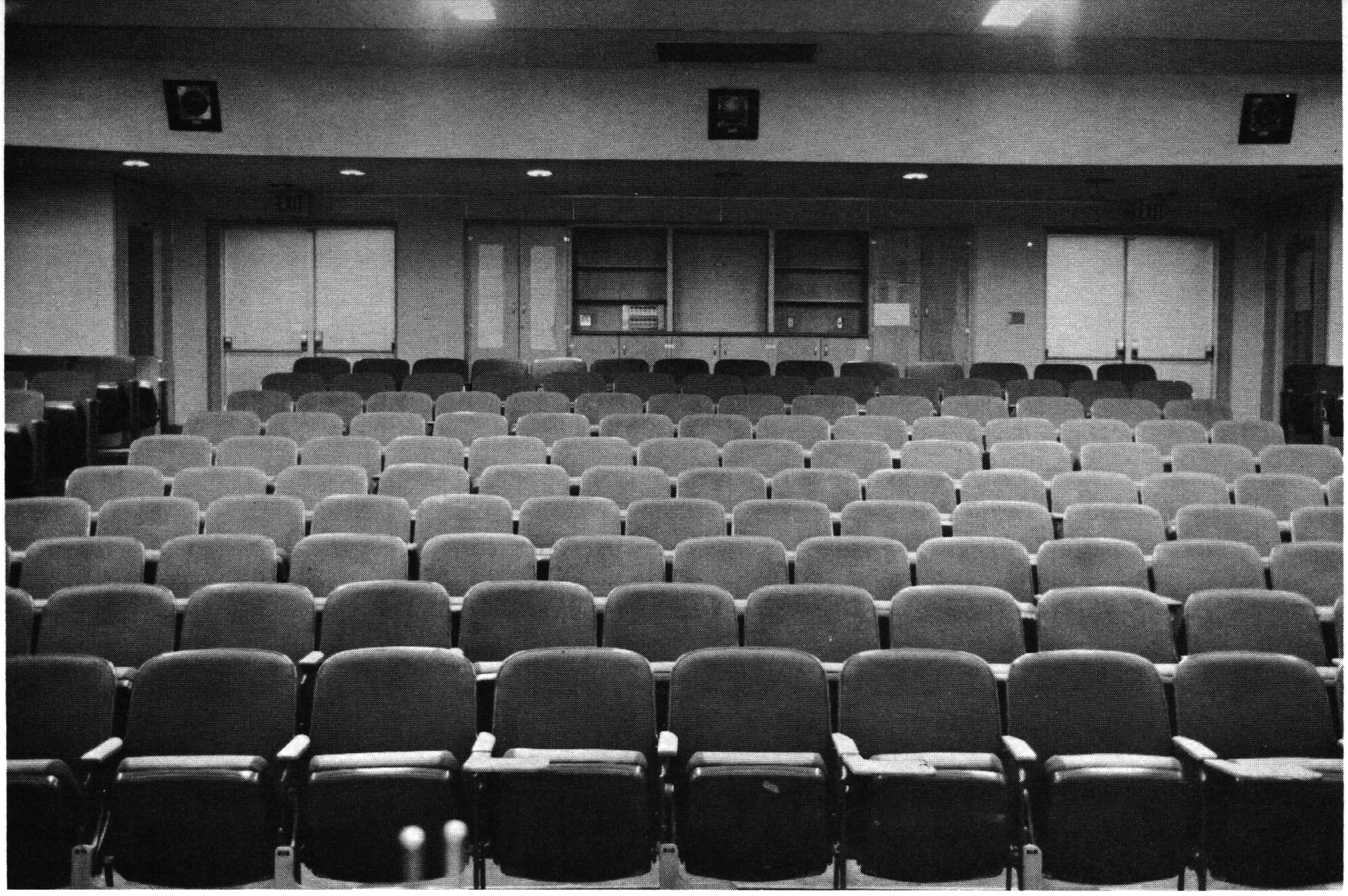
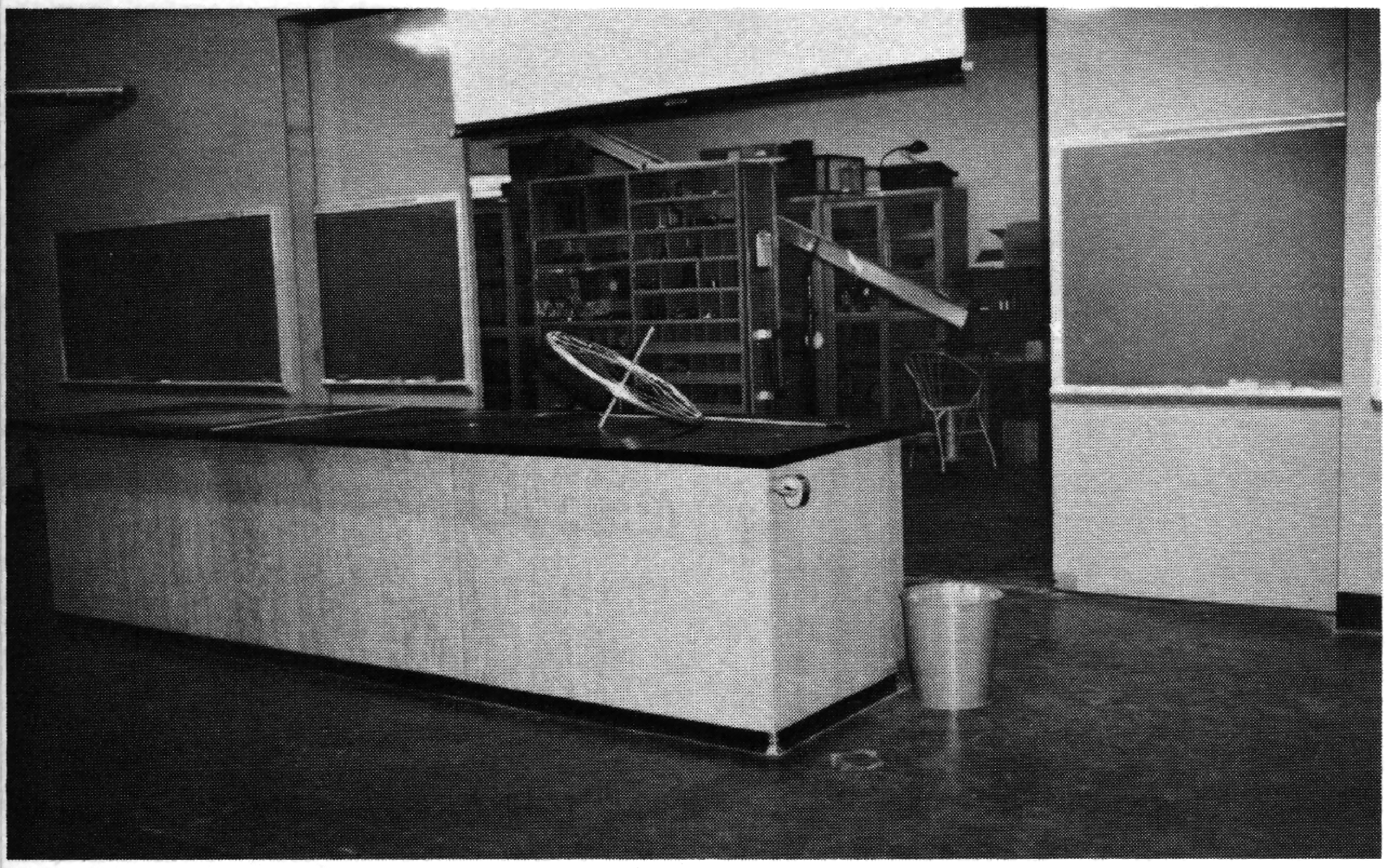
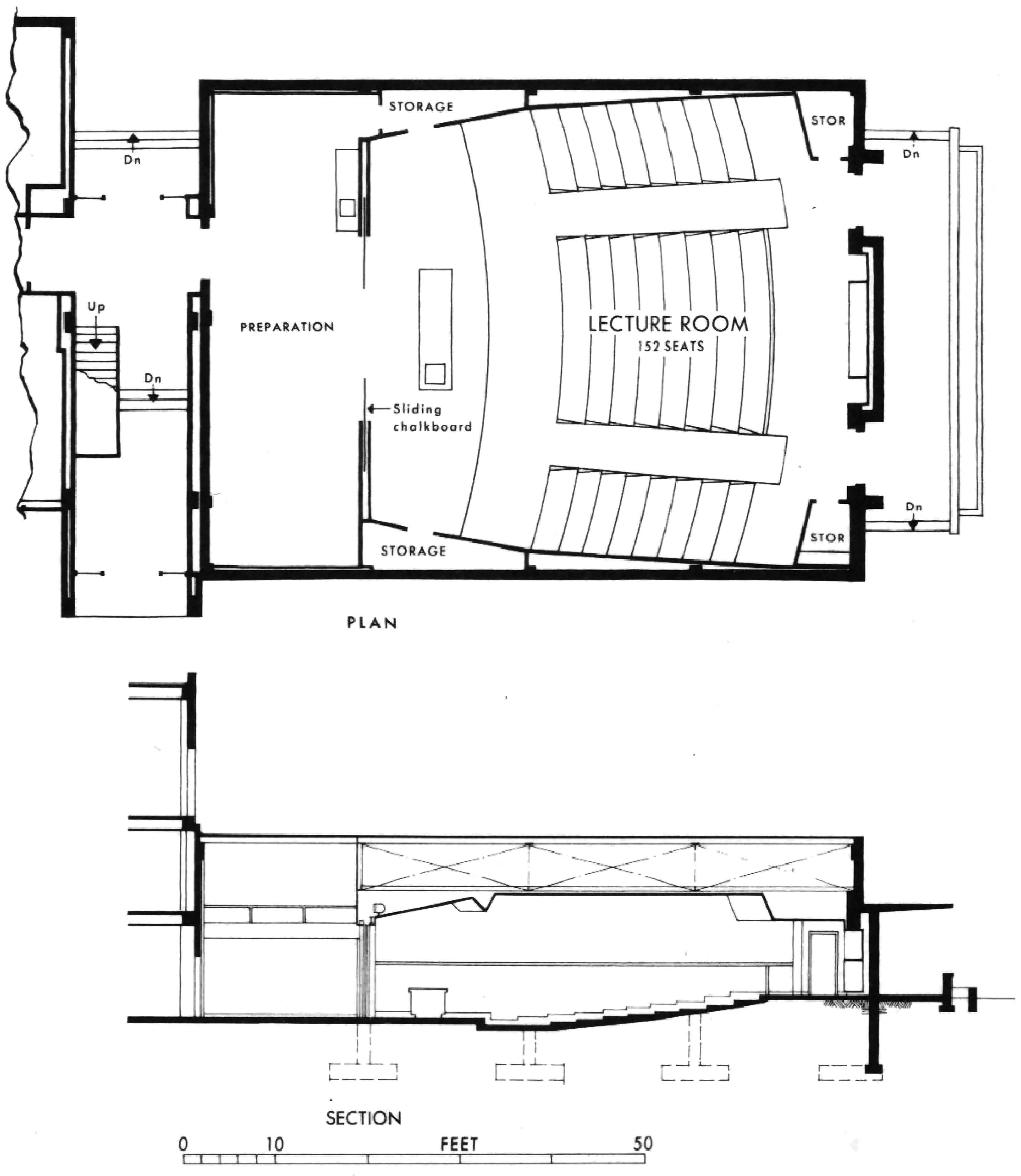


Figure 5. Lecture room, Physics Building, University of Florida (Chapter 4, Figure 3). Alternate rows have seats of different widths to provide better visibility.



Lecture table is mounted on an 8-inch platform. Storeroom is visible through sliding doors behind table.


STORAGE
STOR
Dn
Dn
Up
Dn
PREPARATION
LECTURE ROOM
152 SEATS
Sliding chalkboard
STORAGE
STOR
Dn
PLAN
SECTION
0
10
FEET
50

The 218-seat lecture room in the new Physics Building at the University of Florida (Figure 5) has a slope that is about the same as that in Figure 4c, and the lecture table is also mounted on an 8-inch platform. The rise per row increases from 3½ inches at the first row to 5½ inches at the 10th row—a total rise of only 3½ feet. The physics staff believes that this slope together with the 8-inch platform is quite adequate for good visibility. Since the slope of the room is small, ramps are used instead of steps in the aisle, and the ramps are covered with cork to eliminate slipping.

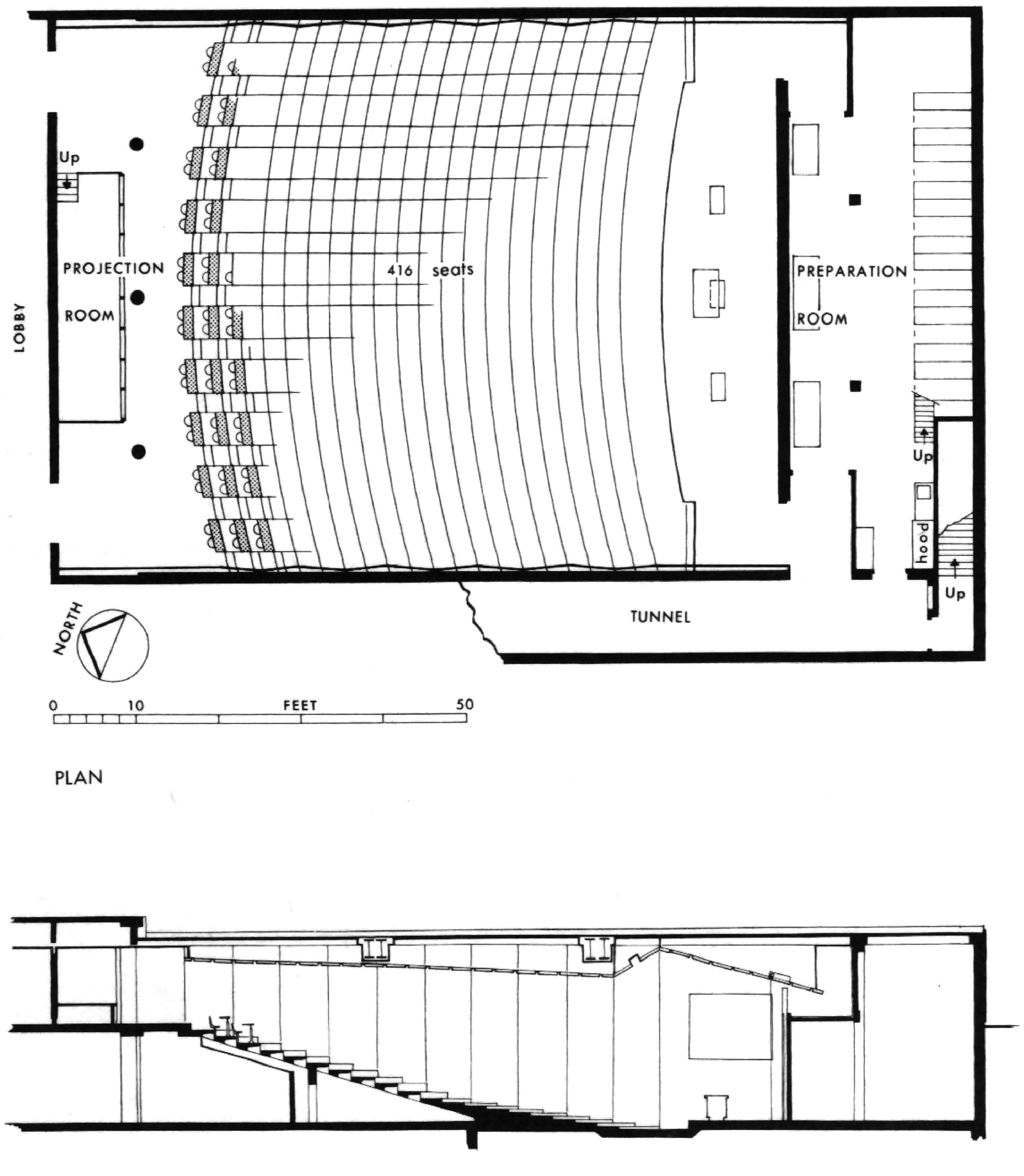
In spite of the fact that better sight lines result if the slope of a lecture room increases toward the rear, most small physics lecture rooms have a constant slope—a compromise that is made to simplify construction. Table II gives data on the slope of some selected lecture rooms.

Acoustics

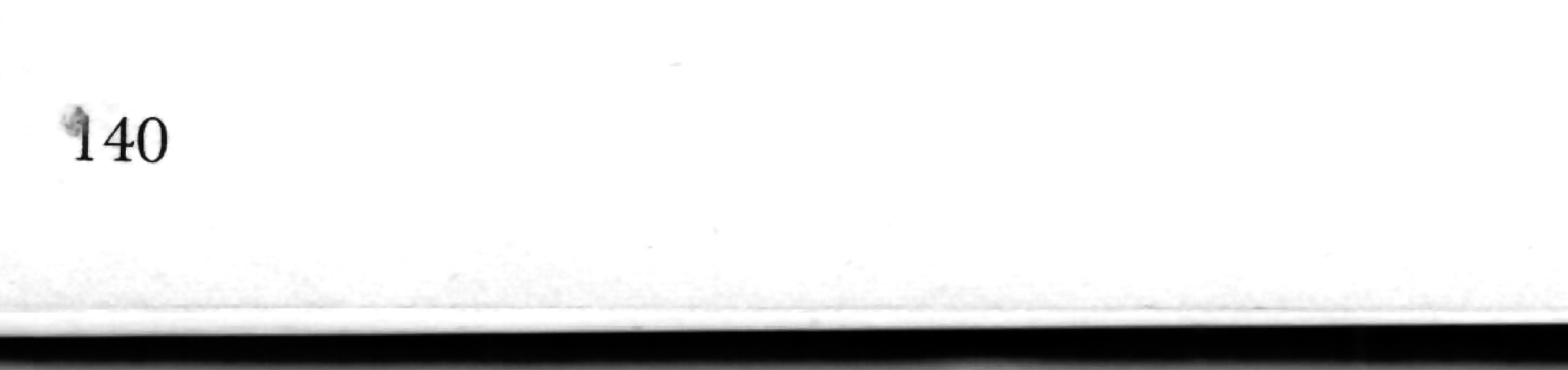
A lecture room that is properly designed may be able to accommodate a maximum of 500 students without the necessity of sound amplification for a good lecturer. However, good lecture room acoustics for an audience of this size can only be achieved when all acoustical designs are optimum. The number of persons to be accommodated not only determines the floor area required for seats but also the room volume for good acoustics. Room volume should be between 125 and 150 cubic feet per person. If it is less than this, ceiling height will be too low to be an efficient reflector of sound to rear seats. Furthermore, with less volume, ventilating noise will be greater because first, the smaller volume of air will have to be circulated more rapidly and second, noisy air vents in ceiling will be closer to students.

Table II. Slope of Selected Lecture Rooms

Lecture Room	No. of Seats	No. of Rows	Distance between Rows (Inches)	First Row to center Lecture Table (Feet—Inches)	Rise per Row (Inches)
Brigham Young Univ.	181	7	36	7–0	17
Univ. of Calif.—Le Conte Add.	225	12	36	8–0	12
Colorado St. Univ.	316	14	37	4–0	9
Univ. of Florida (8″ platform)	240	10	34	12–0	3½ to 5½
Harvard—Burr Hall B	377	11	33	13–6	21
Univ. of Kansas	100	10	38	8–0	3
Univ. of Maine	244	13	32	8–9	6
MIT Compton Lect. Hall	416	20	33	9–0	5 (9 rows) 9½ (11 rows)
Pomona College	140	10	40	8–0	11½
Stanford Univ. B	159	9	35	7–0	11
Swarthmore	200	13	32	6–6	5
Univ. of Texas	180	11	34	5–0	12½ to 16
Univ. of Virginia	195	15	38	8–0	9



PLAN



Shape of Lecture Room. The shape of the lecture room must be worked out with the architect at an early stage in the planning since it influences the acoustics in several important ways.

(a) The seats should be laid out so that each row is above the row ahead of it—so that each person has good sound lines as well as good sight lines. This, of course, requires a room with a somewhat higher ceiling than would otherwise be necessary but, as already noted, this is an essential requirement for good acoustics.

(b) Wall surfaces near the lecture table should be efficient acoustic reflectors. Chalkboards, hard plastered walls, and wood paneling all have this property whereas drapes and curtains are good sound absorbers and they should be completely eliminated from the front of the room.

(c) The ceiling areas are the most efficient sound reflectors in a lecture room. The ceiling above the lecture table and the central part of the ceiling should be finished with hard reflecting plaster and be completely free of acoustical absorbing materials. The ceiling above the lecture table should be

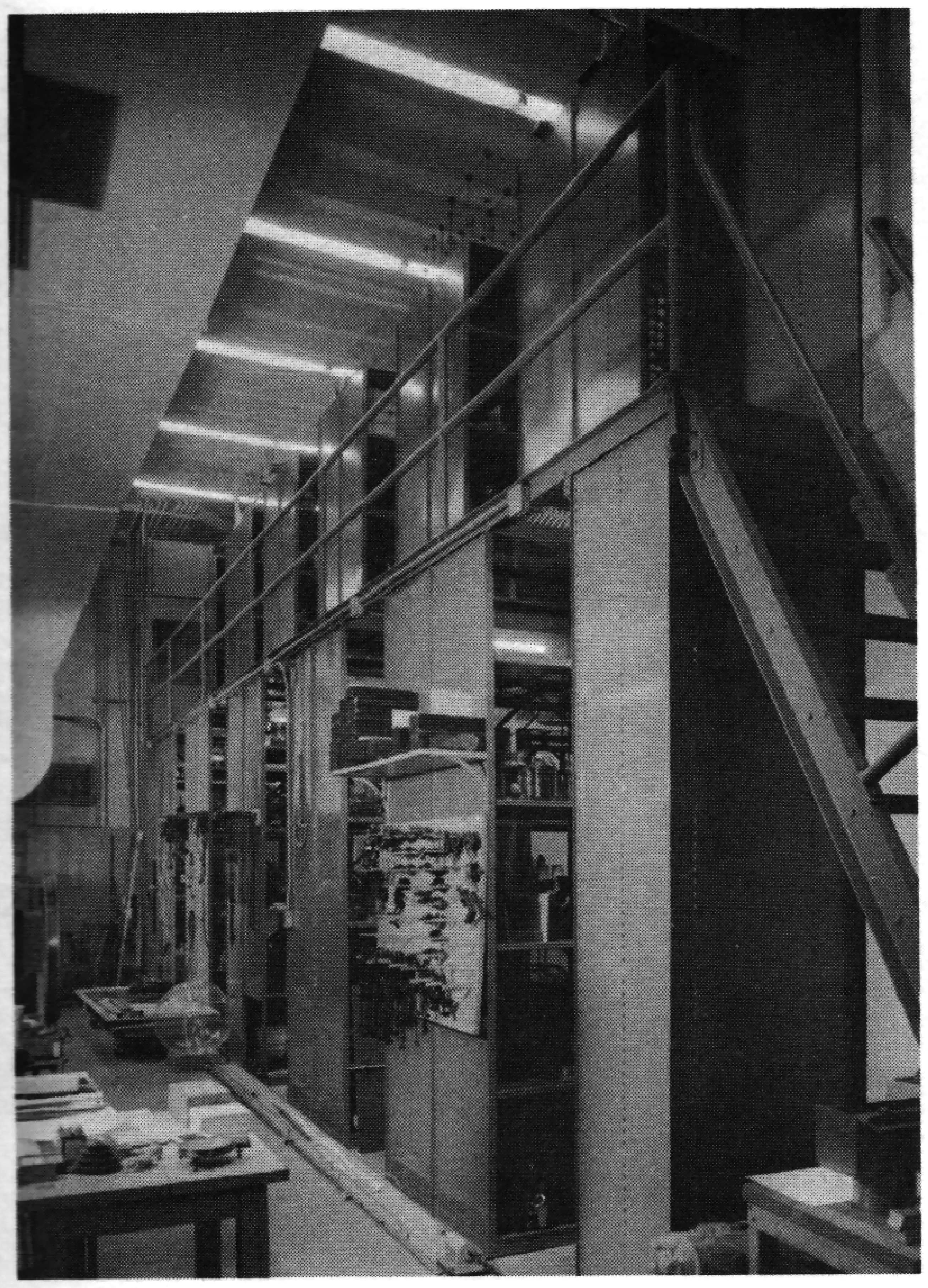
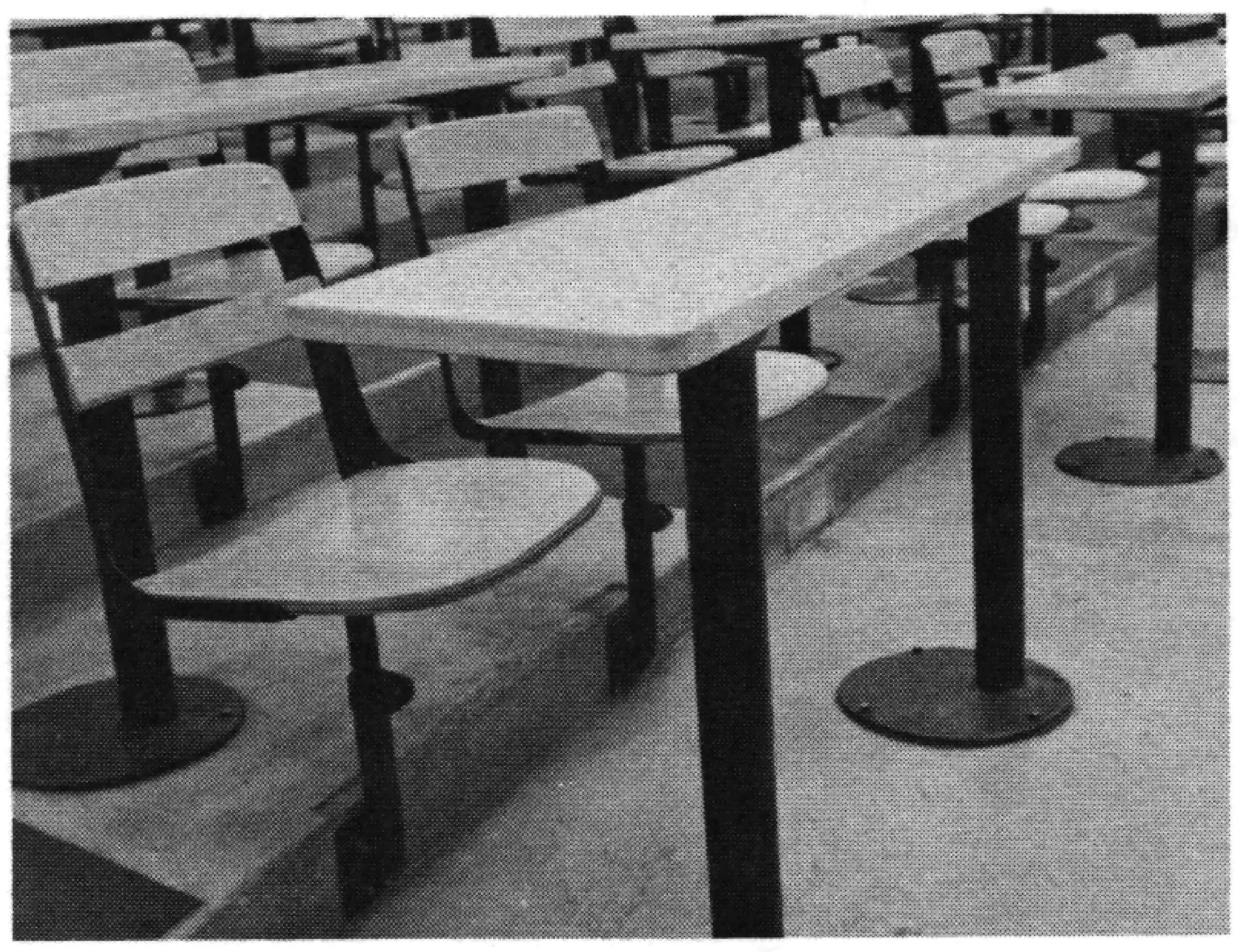


Figure 6. Karl Taylor Compton Lecture Hall, Massachusetts Institute of Technology. Skidmore, Owings and Merrill, Architects, New York. Three photographs show interior view (facing page), storeroom (left), and detail of seating arrangement (below).

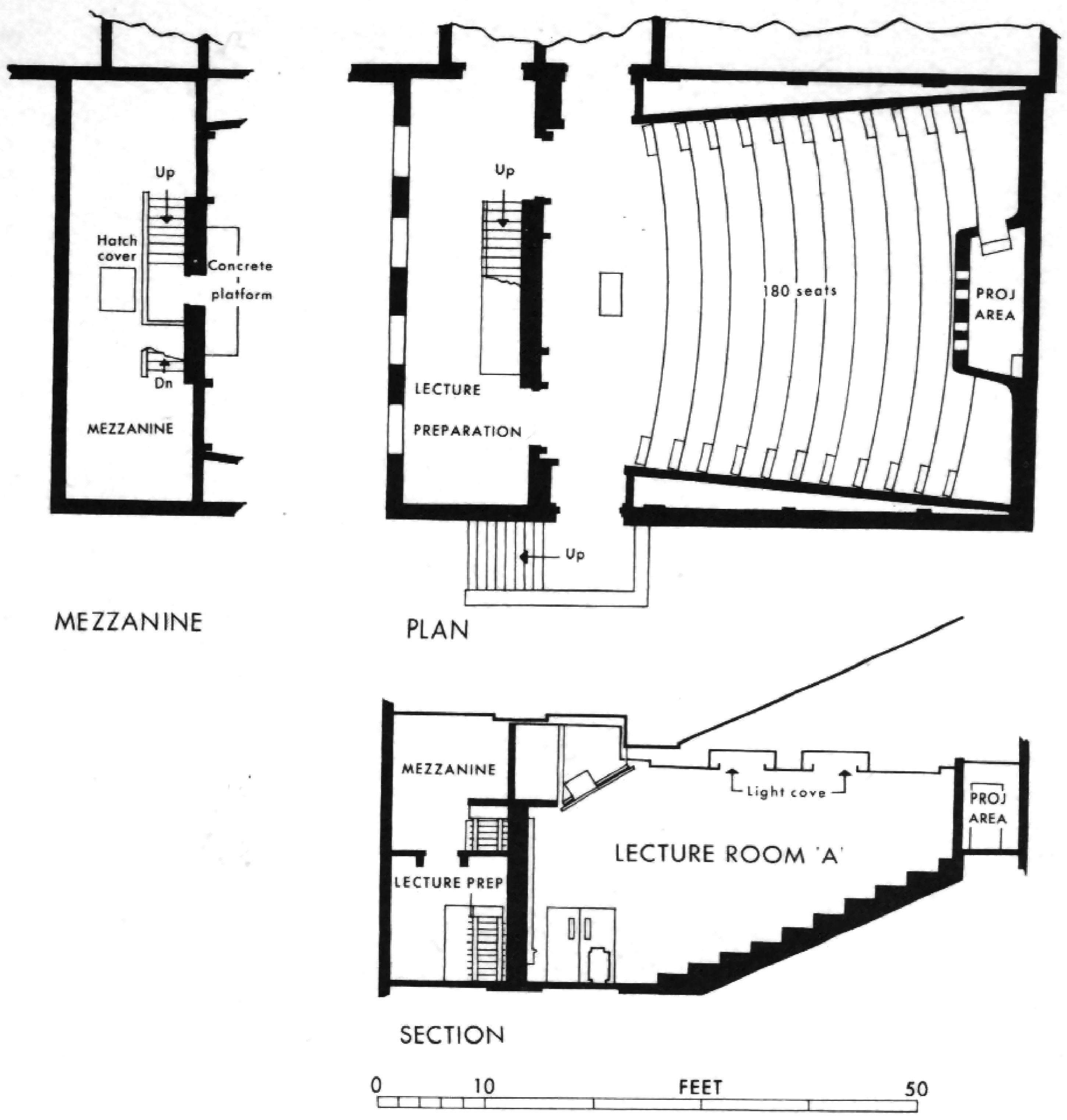


designed at the proper angle to reflect sound from the lecturer out into the audience. Likewise, the central ceiling area can be tilted somewhat to reflect sound more effectively for the rear seats. If acoustical absorbing material is needed on the ceiling, it should be confined to strips along the two sides and at the rear of the ceiling.

(d) The rear wall of a lecture room is a critical acoustical surface. It can cause disturbing echoes at the front of the room if improperly designed. If the rear wall is a flat vertical surface, it should be completely covered above wainscot height with highly absorbing acoustical material. The upper section of the rear wall can be inclined to reflect sound to the rear seats, in which case it should have a hard reflecting surface.

(e) The side walls of a lecture room can be set with advantage at such angles that the room is narrow at the front and flares out toward the rear. With proper design, the lower parts of the side walls when covered with wood or hard plaster become good reflectors of sound to the rear seats. The side walls can be broken up by a series of steps to relieve monotony and also to achieve useful acoustical effects. The flaring out of side walls eliminates seats at the extreme sides at the front of the room. Such seats are, however, poor acoustically and also for viewing lecture demonstrations. Flared side walls also avoid the danger of flutter echoes between the walls. As a rule, upper side wall areas should be acoustically absorbing.

The floor plans as well as the cross-sections and internal photographs of several of the lecture rooms described in this chapter illustrate steps taken to provide satisfactory acoustical characteristics. The 416-seat lecture hall in the Karl Taylor Compton Laboratory at Massachusetts Institute of Technology, shown in Figure 6, has a hung ceiling with two sections tilted at different angles to reflect sound to rear seats. The side walls are stepped to reduce side-wall echoes. Heavy draperies have been provided to cover the large area of glass in front of the large projection booth at the rear of the room to reduce rear wall reflection. The side walls in the lecture halls at Stanford University (Figure 1) are flared to reflect sound to rear seats, and the view in the large 300-seat


Up
Hatch cover
Concrete platform
Dn
MEZZANINE
MEZZANINE
Up
LECTURE PREPARATION
180 seats
PROJ AREA
Up
PLAN
MEZZANINE
Light cove
PROJ AREA
LECTURE ROOM 'A'
LECTURE PREP
SECTION
0
10
FEET
50

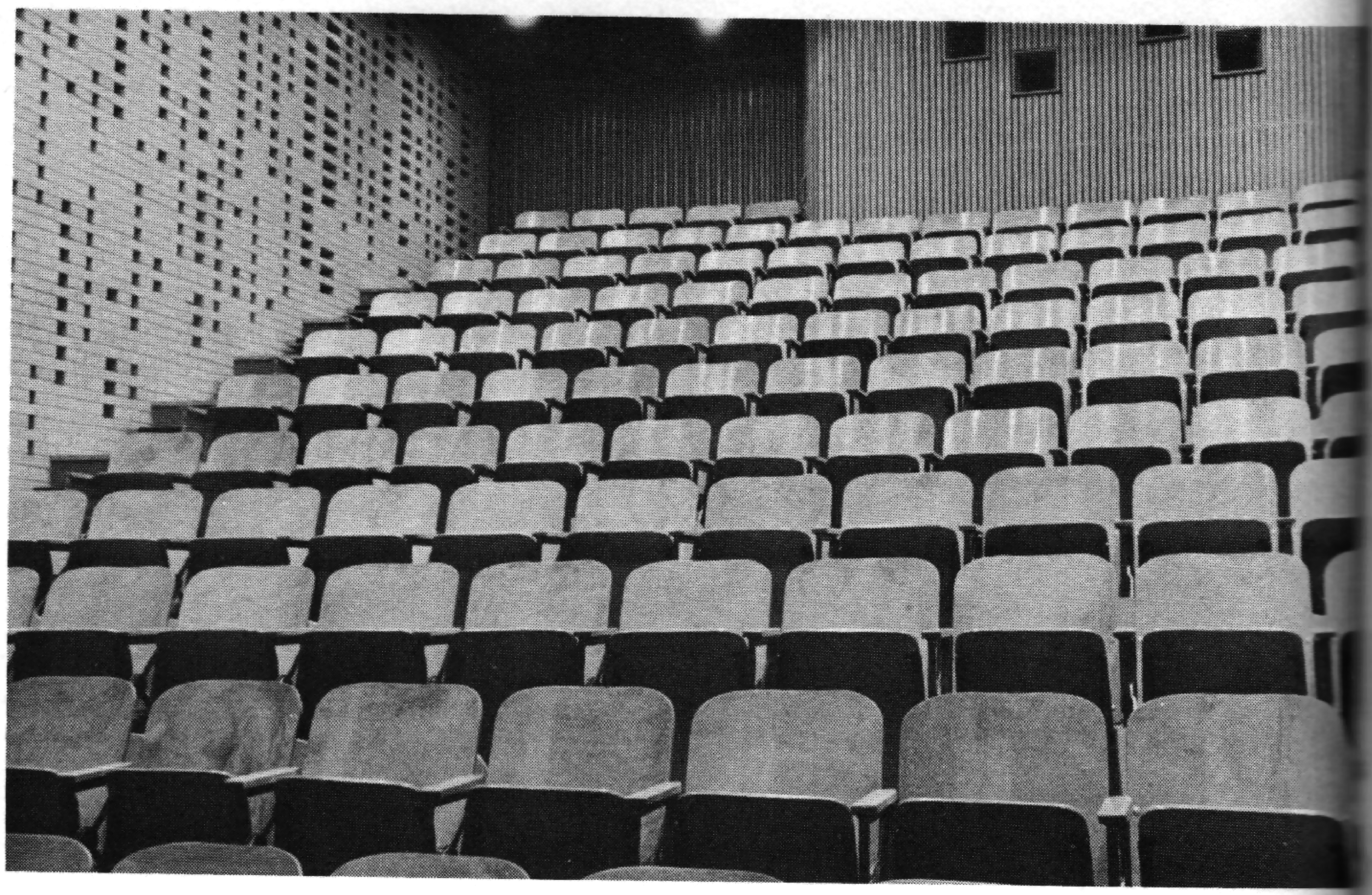
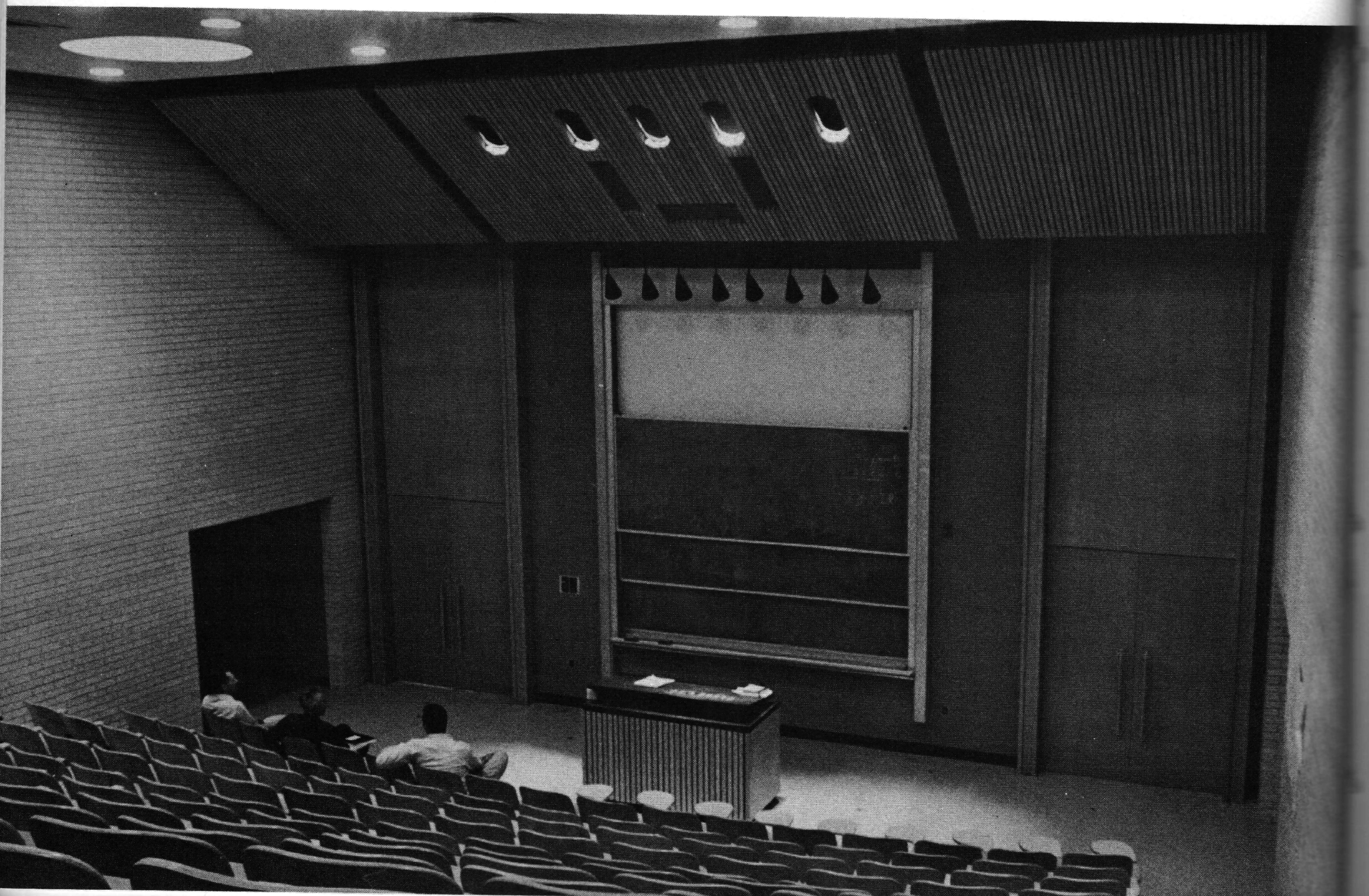


Figure 7. Lecture room in new addition to Physics Building, University of Texas. Fehr and Granger, Architects, Austin, Texas. Note acoustical treatment of side and rear walls (above) and acoustical reflector (below).



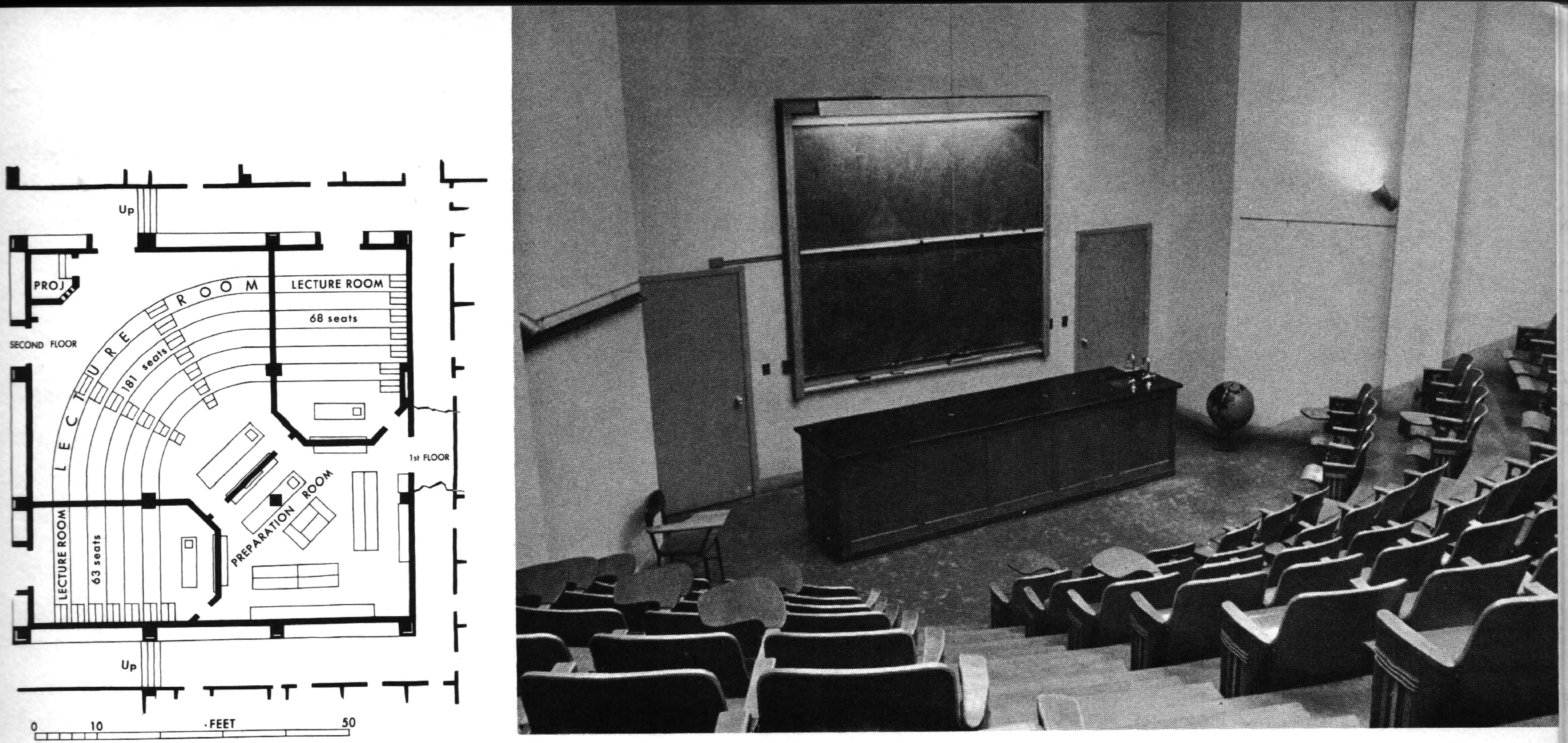


Figure 8. Central physics lecture room, Brigham Young University (Chapter 4, Figure 17). Note the relatively steep rake.

lecture room shows that the ceiling is also inclined for optimum sound reflection. A similar treatment has been provided in the 200-seat lecture room at Swarthmore (Figure 3). The lecture room at the University of Texas shown in Figure 7 has a special reflector above the lecture table—a so-called acoustical cloud—for increasing the sound level at the rear of the room. The side walls over the rear portion are pierced with holes of various size and behind the holes is an acoustically absorbing blanket (Figure 7 c). The vertical wooden strips across the rear of the room are similarly backed.

When a specially shaped lecture room is incorporated in a conventional building, the triangular spaces left over can be put to any one of a number of uses such as riser space for electrical and mechanical services, janitor's closet, and apparatus storage. How this is accomplished for lecture rooms of several designs is shown in floor plans both in this chapter and in Chapter 4.

Some of the advantages of a specially shaped lecture hall can be obtained in a rectangular room by having the lecture table at one corner of an essentially square room. This is done for the central room of the set of three lecture rooms which are served by a common storeroom at Brigham Young University as shown in Figure 8. The two side lecture rooms are rectangular and thus, together with the storeroom, the set of four rooms provide a square group which leaves no odd-shaped space to be accounted for. Three such groups, one each for physics, chemistry, and geology are incorporated within the interior of the Science Building at Brigham Young University, as shown in Figure 17, Chapter 4.

Reverberation. The reverberation time of a room is defined as the time for the intensity of a suddenly terminated sound to diminish by a factor of 10^6 or 60 decibels. Tests show that its optimum value for speech increases somewhat with the volume of the room, from about 0.65 second for small lecture rooms to 0.85 second for the largest lecture halls. If reverberation time is too great, speech becomes unintelligible. If excessive sound absorbing material is used, the reverberation time is too small, and it is difficult for the speaker to be heard.

The approximate reverberation period of a room can be calculated from the well known Sabine Formula:

$$T_r = \frac{0.049\ V}{S}$$

where V is the total volume of the room in cubic feet and S is the number of square feet of "absorption units" in the room. The value of S can be determined by summing up the products obtained by multiplying the area of each surface exposed to sound and its absorption coefficient. Absorption coefficients of various materials and the amount that persons in the audience contribute to the summation can be obtained from acoustical tables such as that given by Beranek.[4]

After using the Sabine Formula to determine the area of sound absorbing material required, the necessary acoustical tile should be distributed as follows. First, all rear walls above the wainscot should be covered. Second, sound absorbing material should be placed on the upper parts of both side walls except for the section near the lecture table. If more absorption is needed to achieve optimum reverberation time, strips of the ceiling along the side walls and at the rear of the room can be treated. *Do not cover surfaces that are designed to reflect sound to rear seats.*

Unfortunately many standard acoustical materials absorb most efficiently in the high frequency region and it is these frequencies which contribute character and intelligibility to speech. Perforated plywood or metal backed by an air space and 2-inch blankets of mineral or glass wool absorb most efficiently in the mid-frequency range (100-500 cycles) and less at higher frequencies. By treating some of the surfaces in this manner optimum reverberation conditions can be approached.

A lecture hall that is properly designed for speech will have a reverberation time that is too short for music. It is strongly recommended that no compromise be made in favor of occasional glee club or orchestra use if the hall is to be for lectures.

Sound Amplification

When a physics lecture room is properly designed acoustically, sound amplification should not be required for a normal lecture. However, it is desirable to install sound amplification equipment for those who may require it, for demonstrations in sound, and for sound movies. Loudspeakers should be located on the wall behind the lecture table and high enough above the lecturer to avoid feedback. Directional loud speakers and directional microphones may be required. A professional installation is needed to give proper sound intensity, even distribution of sound and negligible feedback.

The main amplifier can be mounted in the lecture table with the controls on a panel beneath the overhanging table top. A phonograph which could be used with the same amplifier can be mounted in a drawer in the lecture table. Microphone terminals should be conveniently located at several points beneath the table top. An appropriate switching circuit should be provided so that for sound demonstrations any one or any number of the speakers can be used at a time. A cable should run to the table or booth in the back of the room where the moving picture projector will be located.

Some institutions have available a pocket-size transistorized portable transmitter which together with a receiver and amplifier system frees the lecturer from the bond of a long microphone cable.

Noise Control

The most disturbing source of noise in a lecture room is the ventilating and air conditioning equipment. This can be minimized by a first-class installation which, as described in Chapter 3, provides: (a) proper dynamic balance of all fans and rotating machinery; (b) vibration and shock mounting of all machinery, placed as far as possible from the lecture room; (c) a duct system completely lined on the inside with sound absorbing material and treated on the outside with vibration damping coatings; (d) inlet and outlet fixtures that are properly streamlined to be quiet and placed as far as possible from audience and lecturer. The maximum noise level permitted in the lecture hall should not exceed 35 decibels at positions occupied by people. For additional details see Chapter 25 of the *Heating, Ventilating, and Air Conditioning Guide.*[5]

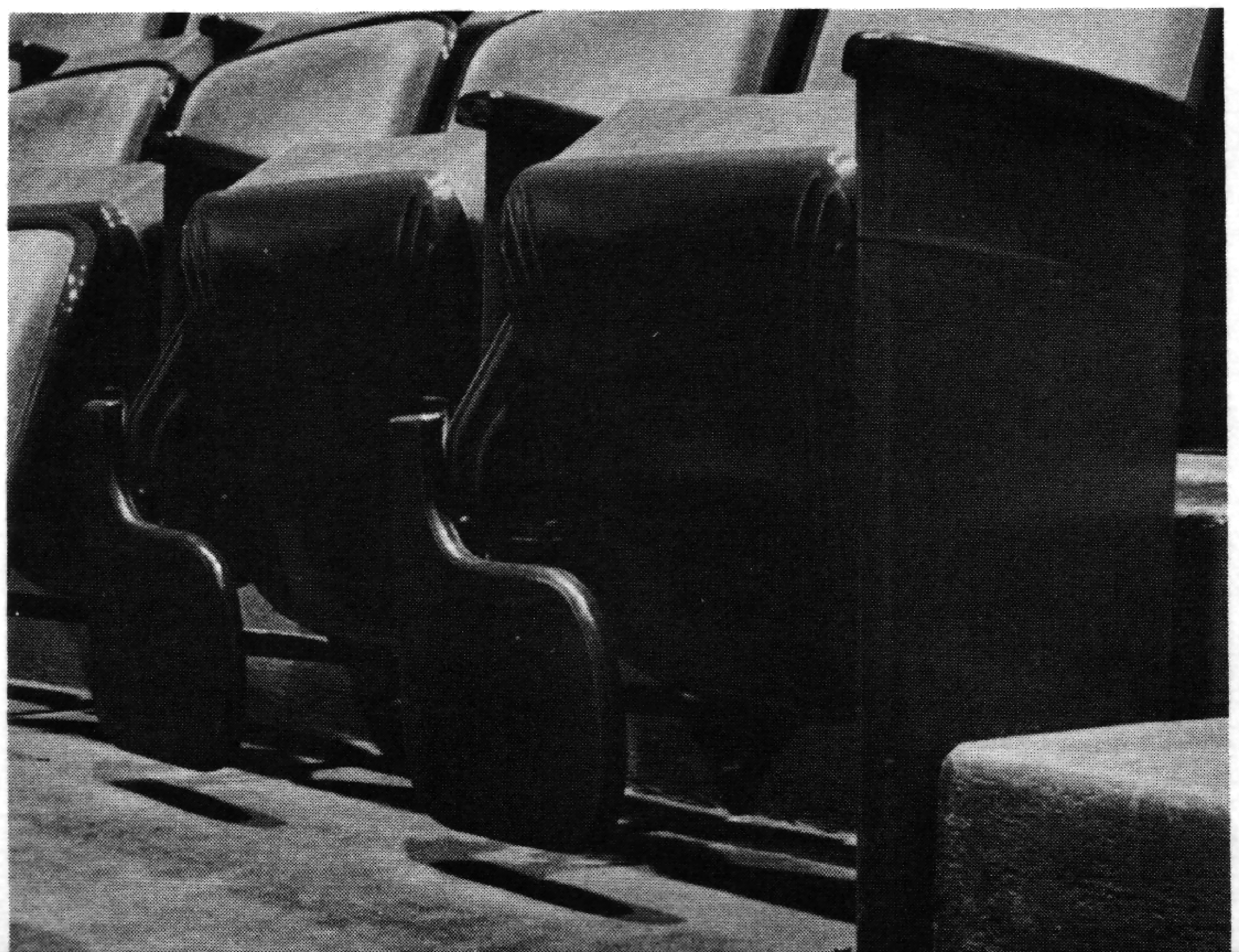
Walls, floors, and ceilings should be of such heavy construction that the disturbance from outside noises will be negligible. Window glass is a poor sound barrier. Lecture rooms therefore should not have windows—both for the control of noise and also to simplify the control of light, as will be discussed later. All doors to the corridor should be good acoustic barriers, and if the corridor is a main one, heavy doors or double doors should be installed. The floors in the lecture room itself and in adjacent corridors should be quiet to minimize noise generated by walking. All corridors and lobby areas adjacent to the lecture room should have highly absorbent acoustic ceilings.

Lecture Room Seats and Writing Surfaces

"We don't want students to be too comfortable; we want them to stay awake." Such a comment was made by a member of the faculty at one college we visited where lecture room seats were rather severe in design. Others desired comfort for their students and therefore equipped the auditorium with seats that had both back and seat upholstered. However, such comfortable seating was usually found where the lecture room was to be used for public meetings as well as for physics instruction. One authoritative architect-engineer has stated that comfortable seats need not cause students to go to sleep if the auditorium is adequately ventilated—assuming, of course, if the teaching is sufficiently inspiring. It should also be remembered that upholstered seats not only provide comfort; they also improve acoustics when seats are only partially occupied.

The several photographs of lecture halls in this chapter illustrate a number of types of seats used in physics lecture rooms in this country. The writing surface provided each student varies from 100 to over 300 square inches. Seats are usually fixed in position; we saw movable chairs used in only one lecture room that would seat over 100 persons. The seats are usually mounted on a single pedestal or they are joined together and supported by a connecting frame as is customary for theater seats. Where possible, seats should be attached to the risers instead of to the floor. Satisfactory brackets for this purpose are available commercially for risers that are 5 inches or more in height. This method of support simplifies the janitor's job of cleaning, for there are no legs to sweep around. His job is simplified still further if tablet arms are fixed and also small in size. Large tablet arms which fold down are usually so close to the floor that they interfere with sweeping. Fixed tablet arms must be small to permit free passage along a row unless more space is allowed between rows. Figure 9 shows seats equipped with fold-down tablet arms mounted on the risers in the Stanford University physics lecture room.

Figure 9. Upholstered seats in Stanford lecture rooms are mounted on risers to simplify cleaning.



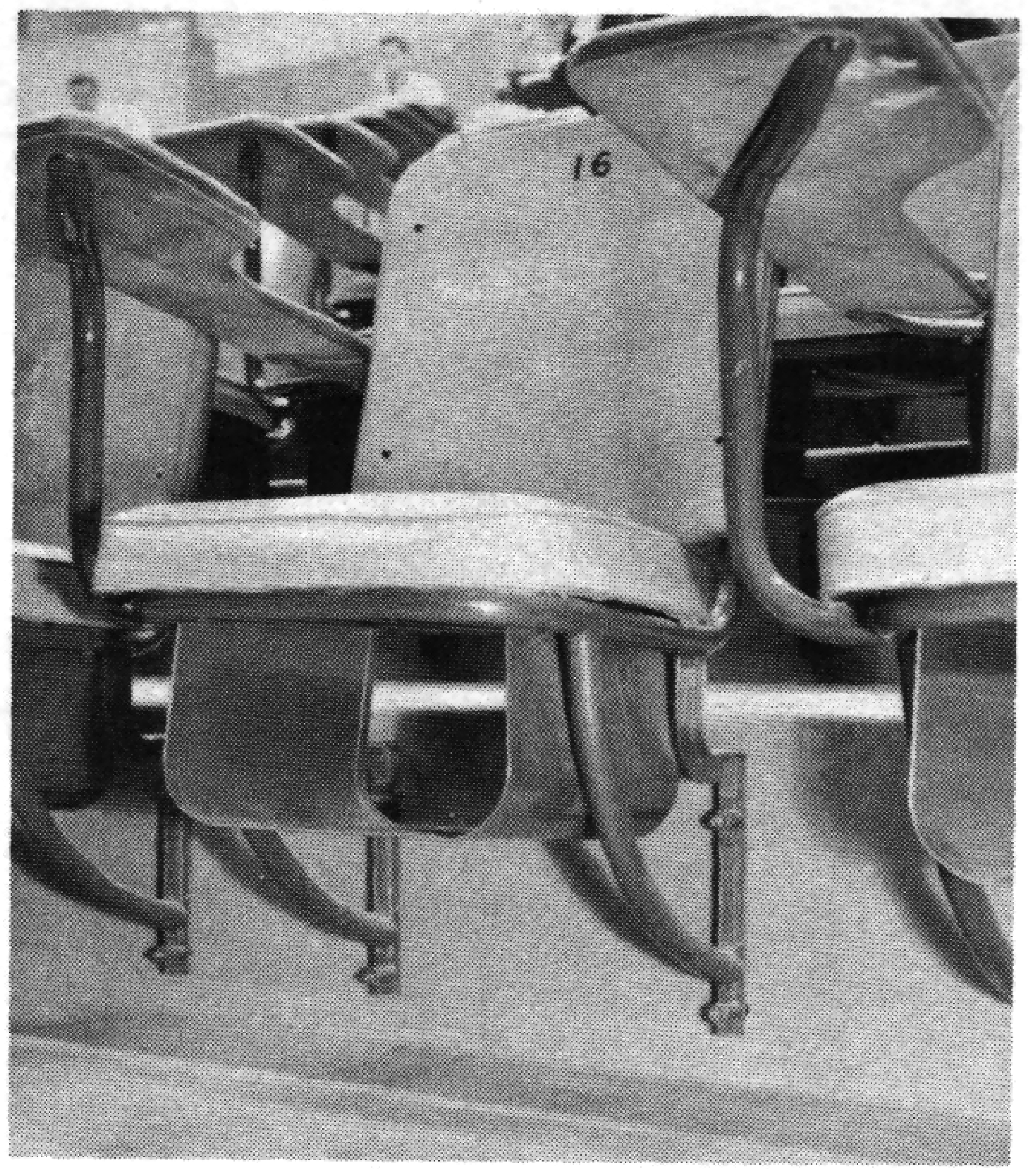


Figure 10. Seats in LeConte Hall lecture rooms at Berkeley are mounted on risers and have racks for books underneath.

Figure 11. Lecture hall at Air Force Academy has long continuous writing surfaces and moulded plastic swivel seats.

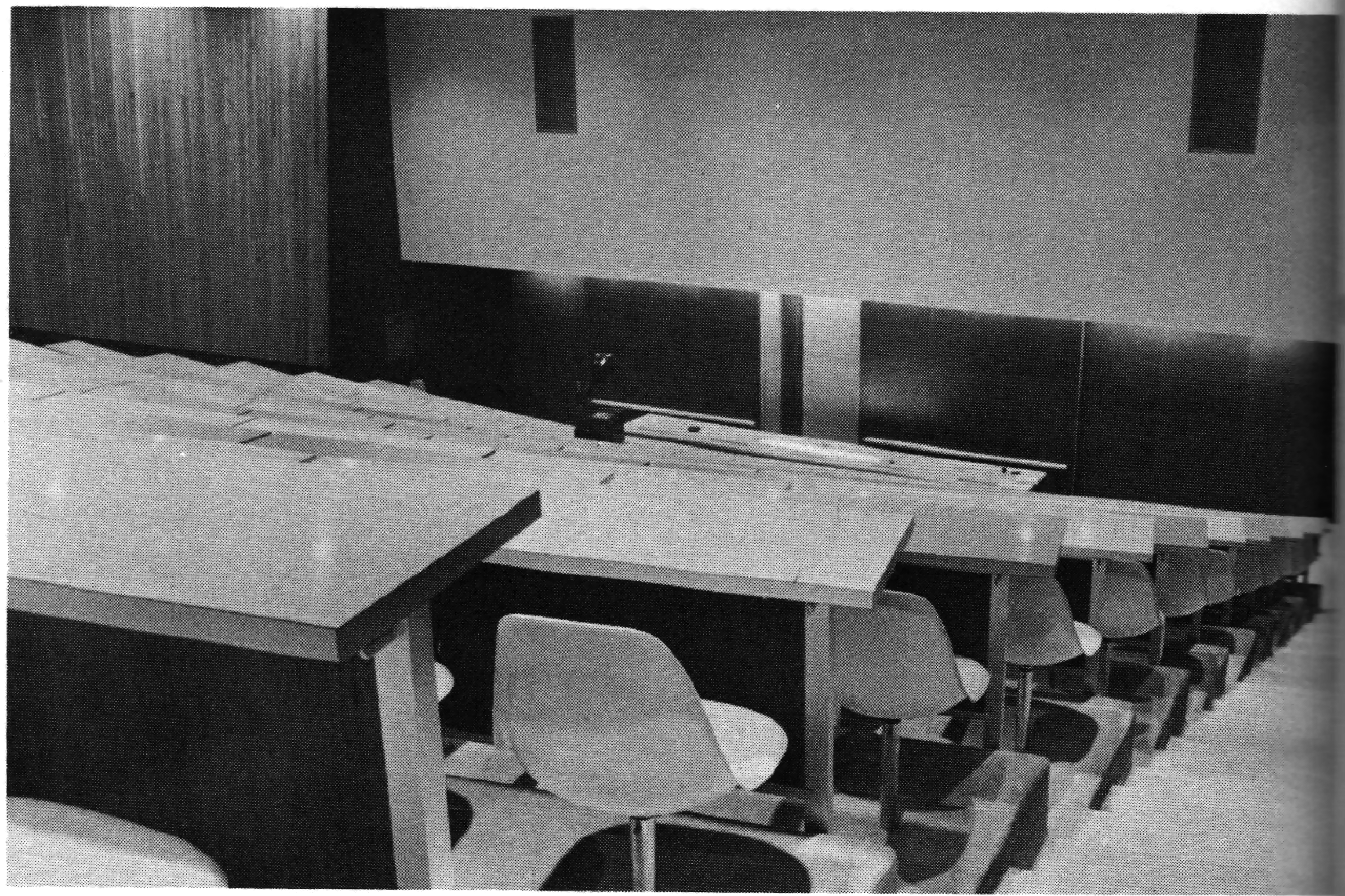


Figure 10 shows how individual seats with fixed tablet arms are similarly riser-mounted in the LeConte lecture room at the University of California at Berkeley.

Notice the large writing area provided each student in the Karl Taylor Compton Lecture Hall at Massachusetts Institute of Technology (Figure 6) and how seats are supported on the risers. Two students share a table, 15 by 48 inches—360 square inches of writing surface per student. Each table is mounted on two metal pedestals which are off center to provide leg room. Each chair is mounted on a single pedestal and is adjustable in height. No student needs to walk in front of another student to reach his seat, for each is on an aisle. Although aisles can be narrow, this type of installation is somewhat more prodigal with space than conventional seating—the floor area required is about 25% more.

Writing surfaces that run the entire width of the auditorium are used in one of the lecture rooms at the Air Force Academy (Figure 11). The shaped seats are plastic and can swivel. Here long tables are supported by attachment to risers, and seats are mounted on horizontal platforms. Sufficient room is left between rows so that students reach their seats by walking behind them. This lecture room will seat 240 persons, while a room with the same floor area that has conventional tablet arm seats will accommodate 400. A continuous writing surface also has been installed in the physics lecture room at Spring Hill College and conventional chairs have been provided for seating, as shown in Figure 12.

The use of long writing surfaces is common in Europe. Long benches are sometimes installed, permitting more students to be crowded in when necessary. Figure 13 shows the seating in the physics lecture room at the Swedish Technical Institute, Stockholm, with its continuous fixed writing surfaces for each row and individual fold-up seats. The

Figure 12. Lecture room in the new Physics Building, Spring Hill College, has continuous writing surfaces and conventional chairs.

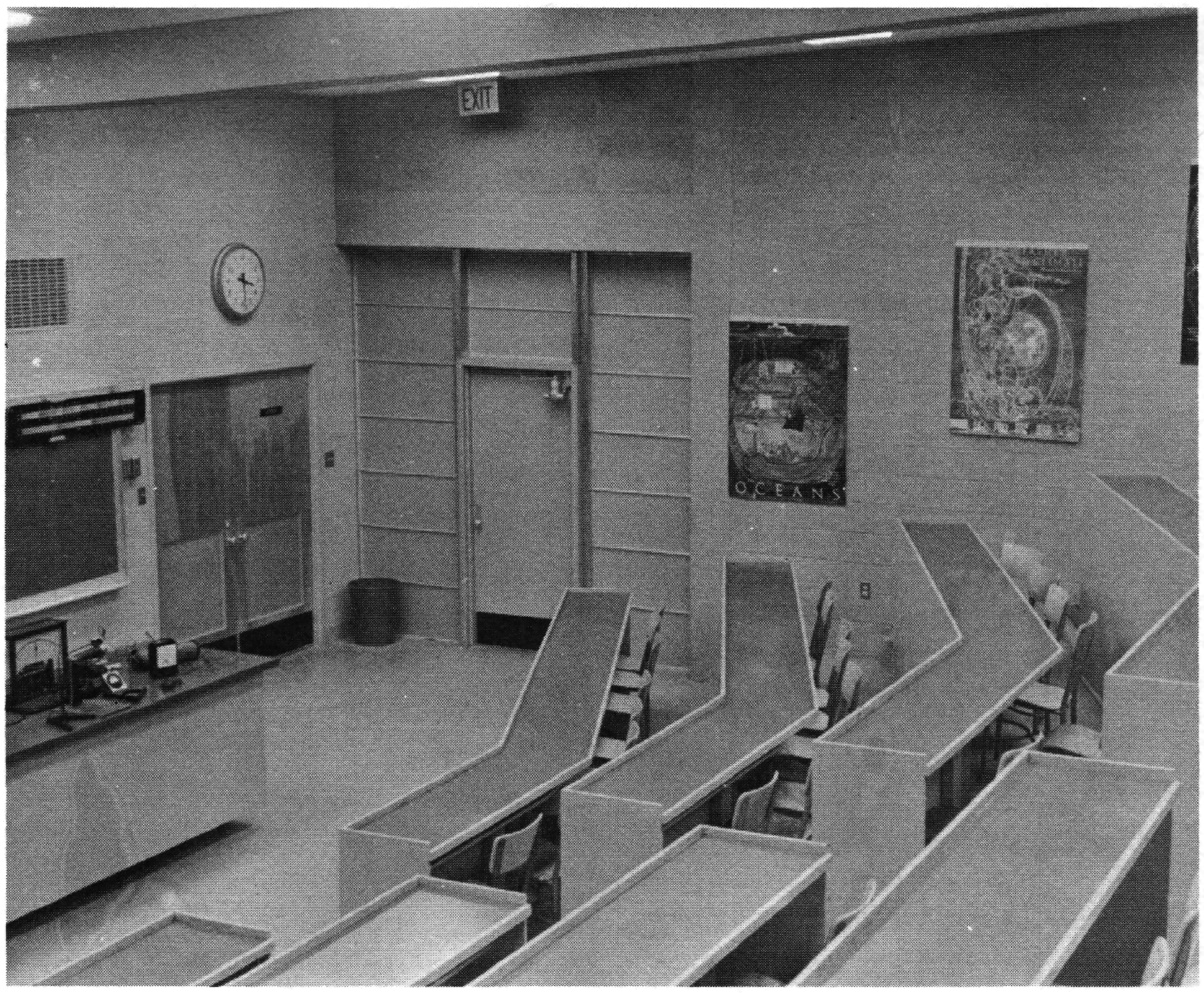
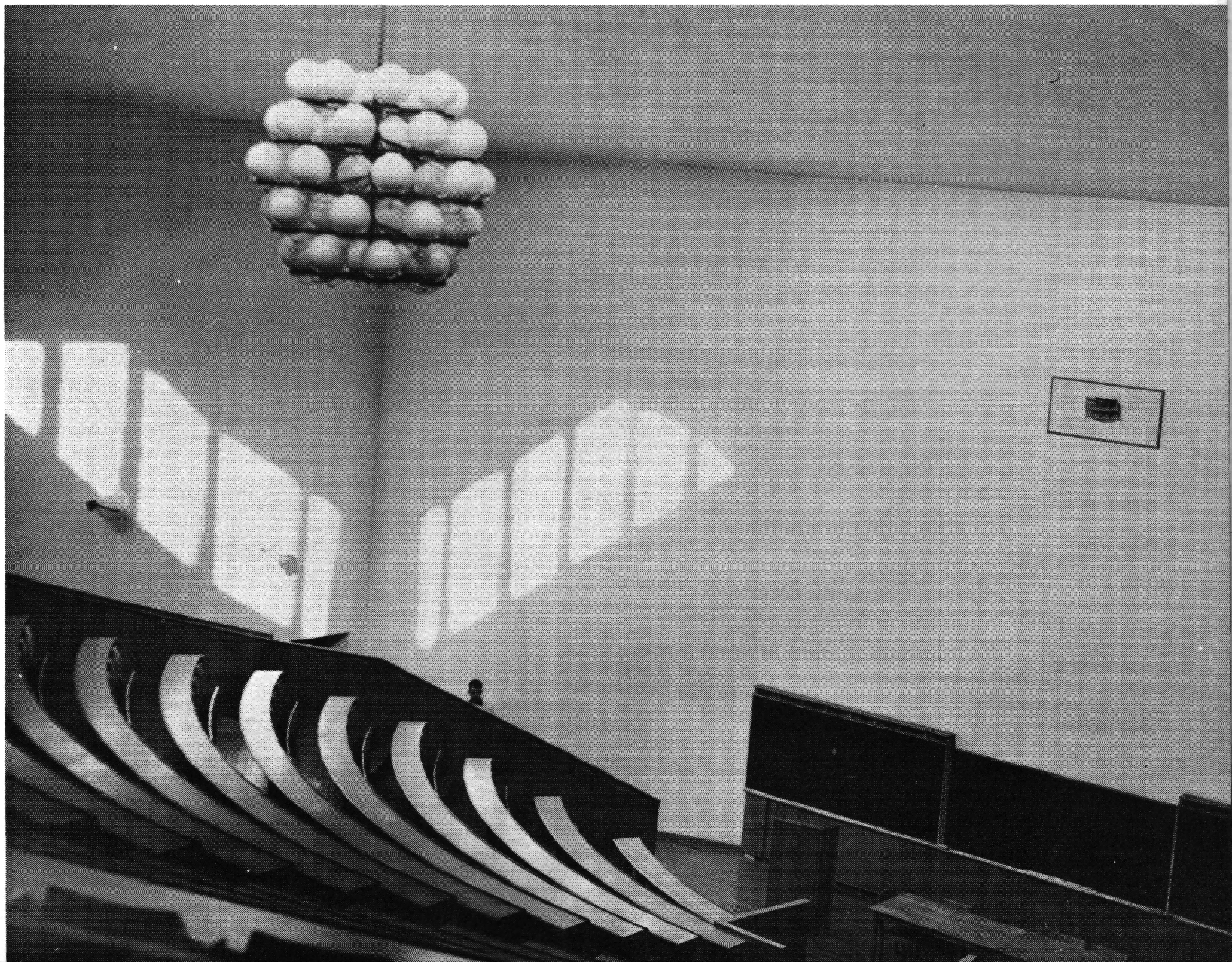


Figure 13. Continuous writing surfaces with fold-up seats in the Swedish Technical Institute, Stockholm.



lecture room in the Technishe Hochschule at Zurich, (Figure 14) provides individual fold-up seats and individual fold-up writing surfaces which are almost contiguous. Quite similar writing and seating facilities are provided in the lecture room at CERN, Geneva, (Figure 15).

Seating Layout

The seat and aisle layout for a particular auditorium is determined not only by the shape of the room, but also by several other factors involving more subjective judgement. One may desire to have students face the lecturer squarely; the rows must then be curved. If one desires to be able to space students economically to minimize the possibility of cheating in examinations, seats in successive rows must be directly behind each other. This can readily be accomplished in a rectangular array of seats or in a section where successive rows have the same curvature if the aisles are parallel. An odd number of seats in each row improves the economy in that the end seats can then both be occupied. On the other hand, if the slope of the auditorium is small, an over-riding concern may be the visibility of the demonstrations; it may be desirable to stagger seats in successive rows. The latter procedure is used in the center section of the lecture room at the University of Florida (Figure 5c). It is interesting to note that even though seats are staggered along the center line, successive rows contain the same number of seats—an arrangement made possible by using seats of non-uniform width in alternate rows and non-uniform spacing between seats.

Aisles are necessary evils since they use up space. Many designers avoid a center aisle since this uses up the most valuable space. If an auditorium is not too wide, two aisles are adequate, one at each side wall. However, at Pomona College (Figure 2) a wide center aisle was desired. The physics staff frequently uses this area for optical projection equipment and for miscellaneous demonstrations. Special electrical outlets are installed in risers adjacent to the center aisle to provide power for such equipment.

One must also consider local building codes in planning aisles. Codes frequently specify the maximum number of seats that a person would have to pass in order to reach the aisle from his seat—this number is usually seven for theaters. Codes may also specify the maximum slope that a ramp can have beyond which steps must be employed.

When the rise between successive terraced rows is such that an intermediate step is required, this step should have the same width as the remaining portion of the terrace. We have heard complaints where this rule has not been followed. Walking up or down steps of varying width is not only awkward but may be hazardous.

The location of doors used by students must be given careful consideration. Many lecture rooms have one or two entrances in the front of the room, and latecomers entering by way of these doors interrupt the class by diverting the attention of students and occasionally by admitting light from the hallway during demonstrations or the showing of films. Main entrances should preferably be in the rear of the room. Hooks for hats and coats can also be located in the rear and the area may be screened from view. The late student can then enter and hang up his coat, and find his seat with less disturbance to the rest of the class. (Doors to the preparation room will be discussed later.)

Lighting

USE OF DAYLIGHT. The need for daylight in lecture rooms is a thing of the past. Most of the lecture rooms in recently constructed buildings are windowless. The exclusive use of artificial lighting simplifies the problem of darkening the room when slides are to be projected or when demonstrations require a low level of illumination. The elimination of windows also helps to reduce the noise admitted from out-of-doors as explained earlier.

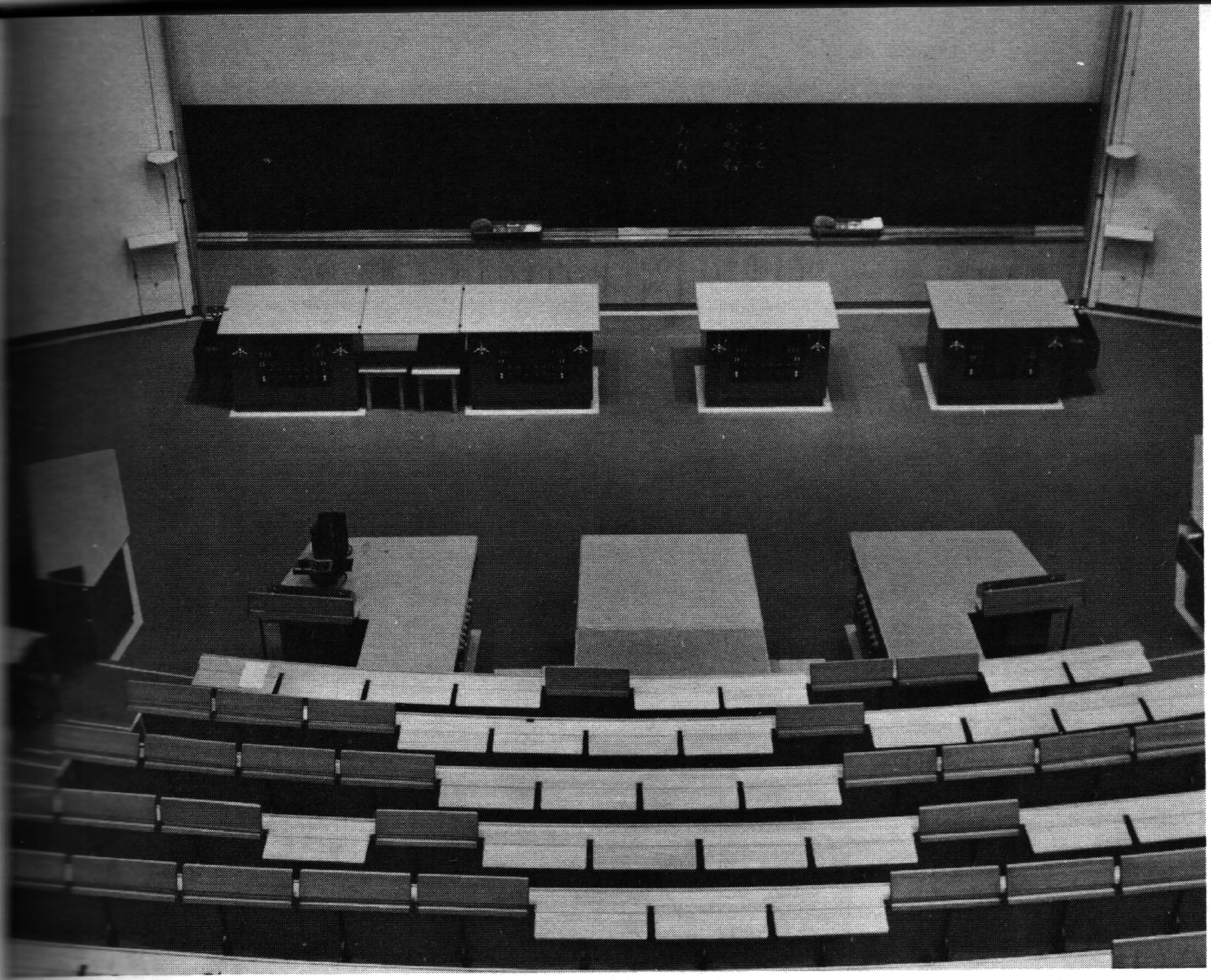
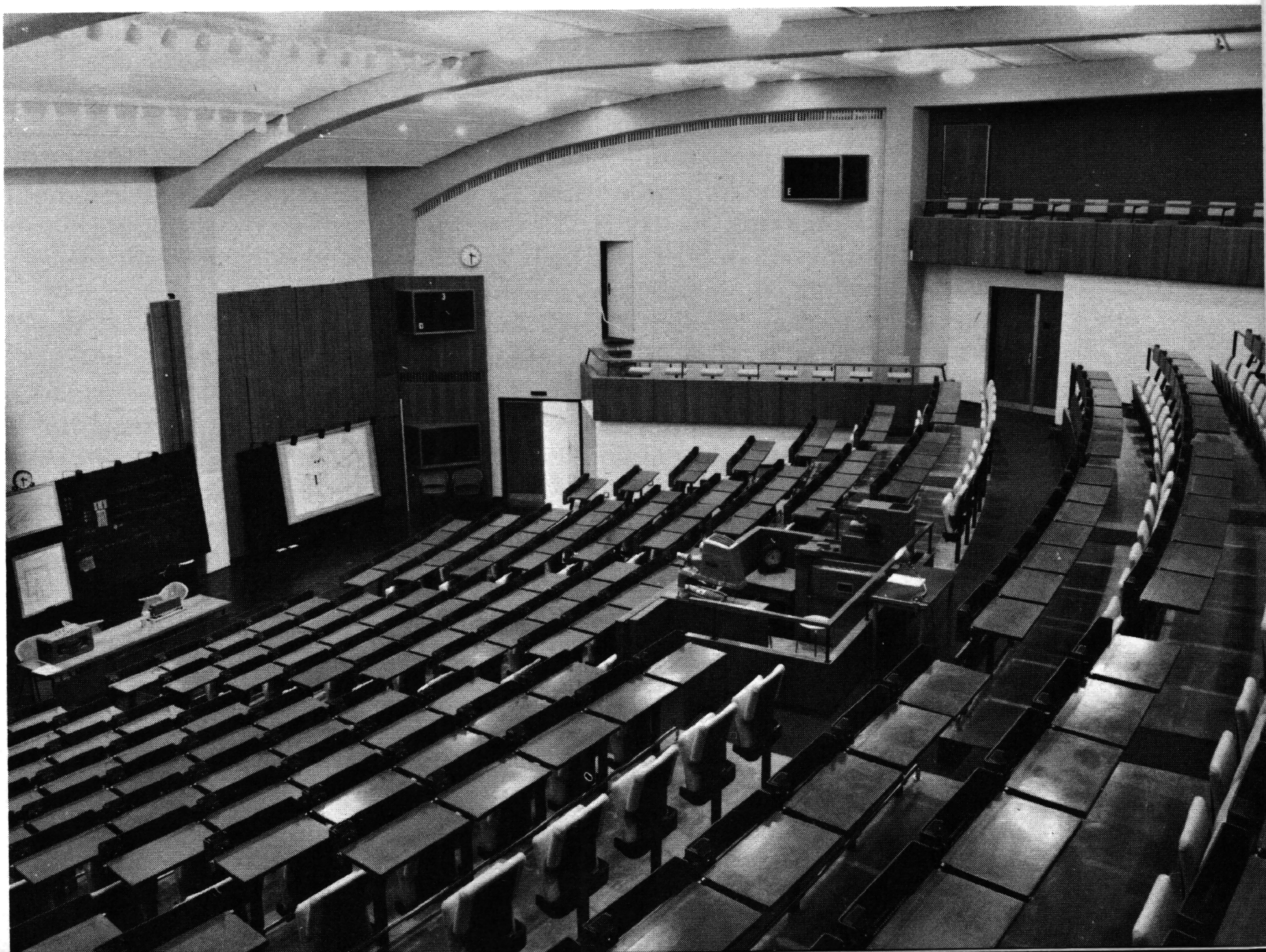


Figure 14. Seating with fold-up writing surfaces in the Technische Hochschule, Zurich. Note large power-operated chalkboard, four fixed lecture tables, and consoles in front of seats where lecture assistants control lights, chalkboard, and miscellaneous projectors.

Figure 15. Lecture room at CERN, Geneva, Switzerland.



Skylights, together with elaborate devices for covering them, were sometimes provided in buildings of an earlier vintage. Many of these skylights have now been permanently darkened because the mechanism for closing them was too slow or too noisy in operation.

Various types of manually and mechanically operated devices have been installed to darken windows, draw cords driven by an electric motor to open and close draperies are one possible arrangement. Since it is desirable to have any such closure light-tight, when draw shades are used they should be baffled at the sides. Furthermore, some device should be installed which will prevent the shades from being drawn when windows are open to forestall damage to shades from wind and from contact with windows which open inwards. All such mechanisms are slow-acting and subject to failure. Most physics teachers, therefore, prefer that the lecture room be without windows. Special attention, of course, must be given to providing suitable ventilation and illumination when windows are omitted.

Level of Illumination. The level of general illumination in the lecture rooms we visited ranged from 15 up to 70 foot-candles. Although a level of 70 foot-candles has been recommended for school classrooms by the Illuminating Engineering Society (IES), this level seems to us to be unnecessarily high for most physics lecture room purposes. At the other extreme, 15 foot-candles is a bit low. Lights could well be on multiple circuits so that for lectures and note-taking the level is about 40 foot-candles and when close work is required the level can be raised to 60 or 70 foot-candles.

The lecture table and chalkboard both need a higher level of illumination than that at student desks. The added illumination is usually provided by supplementary fluorescent lamps fitted with suitable reflectors and by incandescent spotlights, each on a separately controlled circuit. The IES recommendation for chalkboard illumination is 150 foot-candles. Desirable as this level may be, it was not even approached in any lecture room we visited; 70 to 100 foot-candles is considered adequate.

Local high-level illumination of certain areas of the lecture table by the use of spotlights seems to be preferred to a general over-all high level of illumination—probably because the component parts of a three-dimensional piece of apparatus stand out more clearly when shadows are present. Furthermore, since the direction from which the light comes is important, it is desirable to install spotlights which can be oriented as needed. Commercially available swivel-type spotlights can be mounted on a frame near the ceiling, and, can be turned in the direction desired by means of a long rod.

The special lights required for illuminating the chalkboard and the lecture table should be mounted at ceiling height and somewhat ahead of the lecture table. This location will usually produce a sufficiently uniform illumination over the surface of the chalkboard, a consideration that is particularly critical if TV programs are to originate in the room. Since the acoustical design of a lecture room usually calls for the hung ceiling to change in level along a line which is also a short distance ahead of the lecture table, the chalkboard and lecture table lights can be recess-mounted in the space between the two sections of the ceiling and thus be out of view of the audience.

Dimming. Satisfactory dimming is an important feature in a physics lecture room. It is often desirable to darken the room only partially so that students can still take notes when slides or films are projected or when certain demonstrations are given. This can readily be accomplished when the lights at the front of the room are turned off if the remaining room lights can be dimmed. An illumination level of 2 to 3 foot-candles is adequate for taking notes. If room lights are recess-mounted in the ceiling (usually a hung ceiling), they produce downward illumination only, and the front of the room receives only scattered light. The room lights then do not need to be dimmed as much for satisfactory optical projection.

Dimming can of course be accomplished by turning off lamps in groups. However, it is more pleasant if dimming circuits are used so that the change in illumination is produced less abruptly.

Incandescent lamps can readily be dimmed simply by lowering the voltage across them. For a small lecture room, a manually operated autotransformer, conveniently mounted in the lecture table, is satisfactory. When larger amounts of power are involved, the autotransformer is usually mounted in the preparation room and is motor-driven. Controls which operate relays to provide power for the motor can then be provided at any desired location—at the projection booth in the rear of the auditorium as well as at points convenient to the instructor in the front of the room. Thyratron-controlled rectifiers can, of course, be substituted for the autotransformer.

Fluorescent lamps cannot be dimmed as simply as incandescent lamps. If one attempts to dim fluorescent lamps by simply lowering the voltage, most lamps begin to flicker when the light output has been reduced by no more than one-half. Rapid-start type fluorescent lamps can be dimmed still further by using a special ballast on each lamp to maintain constant filament-heater voltage.[6] Special thyratron dimming circuits have recently been developed which permit the light output from fluorescent lamps to be reduced to 2% of normal without flicker. For this purpose, lamps of the rapid-start type must also be used in conjunction with a special ballast. Dimming controls and corresponding ballasts are commercially available for 120-volt and 240-volt circuits.[7]

Most lecture rooms we have seen use a combination of fluorescent and incandescent lights for general illumination. Only the incandescent lights are dimmed since this can be done rather simply. The fluorescent lights are turned off first and then voltage on the incandescent lights is lowered to the desired level.

Relamping. In designing the lighting of a lecture room, some consideration should be given to the problem of relamping. Lamps will burn out, and it should not be necessary to have to wait until summer vacation before the required scaffolding can be erected. The 120-volt incandescent lamps in the physics lecture rooms at Princeton University are normally operated at reduced voltage (100 volts) to prolong their life. Full voltage is applied only when a higher level of illumination is desired. The circuit of Figure 16 makes it possible to control each 9 kilovolt-ampere load with an autotransformer rated at only 1.5 KVA. To dim the lights much lower, the fixed transformer needs a smaller ratio and the variable transformer must be able to handle much more power.

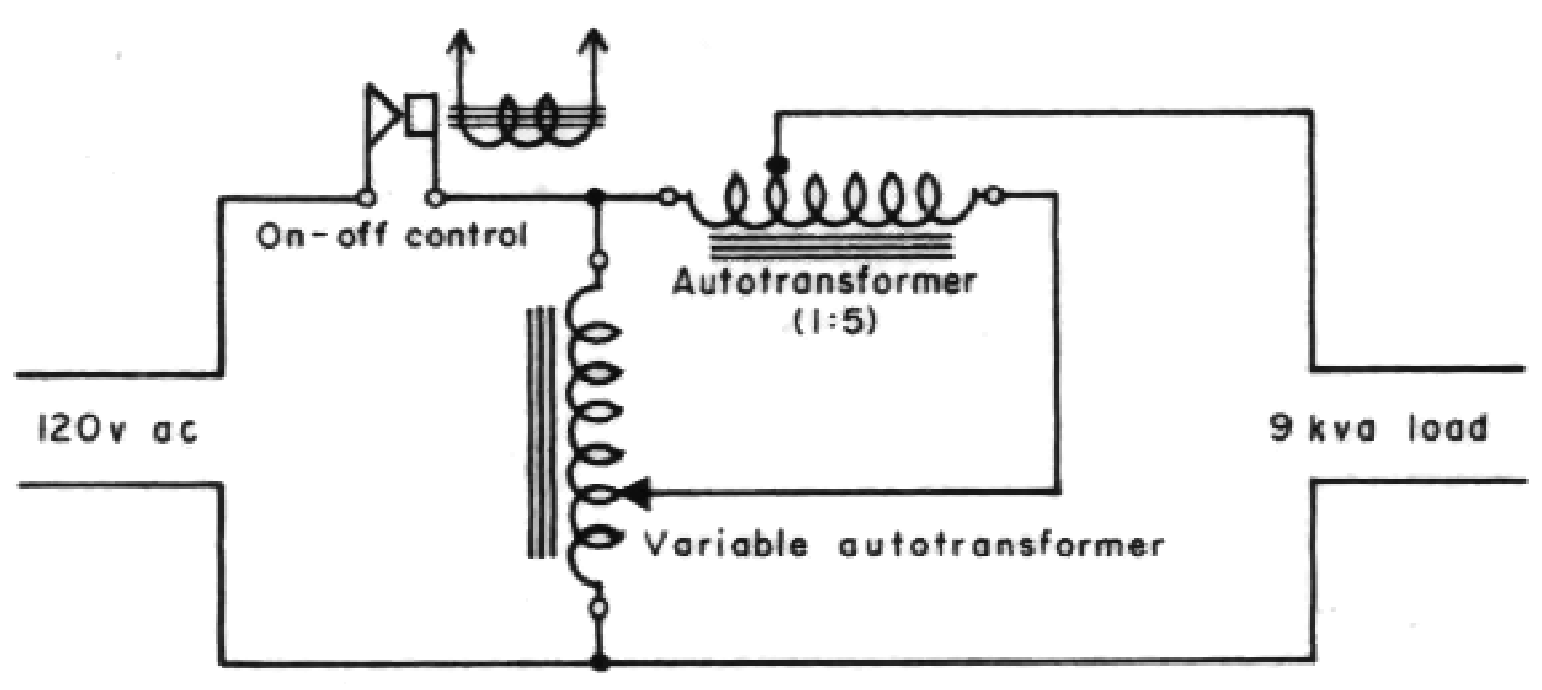


Figure 16. Dimming circuit used in the physics lecture halls at Princeton University. To prolong lamp life, lamps are normally operated at 100 volts and brightened only when more illumination is needed.

The rate of dimming is important. Although eye accommodation takes place slowly, to minimize irritation it is merely necessary to avoid sudden large changes in illumination. Dimming time need be no more than a few seconds. Normal installations for dimming require that the instructor hold a switch closed until the desired level is reached. It is annoying both to him and the students if this time is too prolonged.

Lighting Controls. Lighting controls should be conveniently located and simple to operate. A visiting lecturer should readily be able to find the light switch and understand how to operate it without an extensive course of instruction. We have seen a number of systems which do not meet these specifications. At one college we were informed that students were seldom left in the lecture room and asked to turn off the lights when they left. It was simply too complicated a process to describe in a reasonable time!

Most physicists prefer that the controls for all light circuits be mounted together on a simple panel which is conveniently located beneath the overhanging top of the lecture table. The separate switches for the several spotlights, the chalkboard floodlight, the room lights, and the dimming mechanism would then be grouped together in one place. They should be logically arranged and easy to locate without fumbling in the dark. A pilot light mounted on the panel facilitates this. A transparent plastic button on a push-button switch is easily located in the dark if a pilot light is located behind it. Other switches, for such things as galvanometer lamps and wall-mounted meters, should be mounted on a separate panel so as not to be confused with the light switches.

A latching relay should be used as the master switch for controlling room lights. When such a relay is used with a simple push button switch the lights are alternately turned on and off by successive momentary closures of the switch. The advantage of such an arrangement is that any number of push button switches can be placed in parallel and mounted wherever convenient. As a minimum, a switch should be located at each door, one at the projection table (or booth) in the back of the room, one at each end of the lecture table, and one at each side of the chalkboard. (Perhaps the one at the main entrance should be key-actuated if students are apt to play with it.) It may also be convenient to have a switch on the end of a cable so that the lecturer can have control of room lights near the apparatus he is demonstrating. A cord which is tied to a simple spring-loaded toggle switch can also be used. If the switch is mounted beneath the top of the lecture table and the cord runs around the table and is suspended vertically from the overhanging top, the lecturer can turn lights on or off by a single pull on the cord. A similar arrangement with a cord suspended beneath the chalkboard tray has also been used.

Latching relays can also be used in conjunction with two push button switches to actuate the motors which control dimming. It should be possible to initiate dimming by a momentary closure of the dimming switch and to stop the action by a subsequent momentary contact. A third contact will produce another dimming operation, and so on until a limit switch stops the process. Likewise it should be possible to initiate brightening and to stop the action by successive momentary closures of the brightening switch. By such an arrangement, any number of pairs of dimming and brightening buttons can be connected in parallel and located where desired—at least at each end of the lecture table and at the projection table in the back of the room.

Heating, Ventilating and Air Conditioning

Probably the most frequent criticism we have heard of existing physics lecture rooms has been in the area of heating, ventilating, and air conditioning. Although there is seldom any complaint about inadequate heat, most physics lecture rooms seem to be inadequately ventilated. Ventilation problems are particularly severe when lecture rooms must be used to capacity in successive hours throughout the day—an increasingly frequent occurrence as the student population rises. The only realistic solution is to provide in the initial stage the ventilation required for the maximum use which may be expected of the room. The installation of supplementary blowers and ducts after a building has been completed is seldom entirely satisfactory and is also costly. The methods of reducing noise in a ventilating system and the maximum noise level which should be permitted are discussed in an earlier section of this chapter.

Most of the new physics buildings in the south are air-conditioned. Where a new building is not completely air-conditioned, at least the lecture room is, and this practice is extending to colleges throughout the country. Lecture rooms which are without windows require air conditioning if they are to be used in the summertime almost anywhere in the United States. Since the summertime use of college facilities is increasing, no college or university should design a new lecture room without providing for—as a minimum—the possible installation of air conditioning at a future date. Since lecture rooms have variable heat loads from hour to hour, the air conditioning unit for a lecture room should be a unit system and not a part of the system which serves the rest of the building.

LECTURE ROOM FACILITIES

Chalkboards

Probably the most important single tool for the physics lecture room is the chalkboard. It must have good characteristics for writing and erasing, and it must have sufficient area. Chalkboard materials are discussed in Chapter 3. We will be concerned here with the special problems of lecture room chalkboards.

Most physics instructors would like to have sufficient chalkboard area so that they do not need to erase during an hour's lecture. They either believe that what is written on the board should remain for future reference or that they lose too much time when they have to erase. Considerable effort is required to erase some chalkboards satisfactorily. On the other hand, there are a few instructors who do not feel that a pause for erasing necessarily creates a pause in student learning. And some believe that student attention is better focused on the matter at hand if the chalkboard is erased occasionally. However, such persons seem to be in the minority, since double and triple chalkboard systems with movable sections which slide vertically in ways are being installed in most new physics buildings today. Multiple chalkboards have the added general advantage that material such as outlines, tables, and quizzes can be placed on the board prior to class period and left covered if so desired until needed.

Some instructors like a section of the chalkboard ruled to provide an area for the drawing of graphs. Ruling, however, should be light so it will not eliminate this section of the board from other use.

The advantage of using oversize ⅝-inch diameter chalk in a large lecture hall has been mentioned earlier.

TYPES OF MULTIPLE CHALKBOARD SYSTEMS. (1) Chalkboard systems which slide vertically: Systems in which the movable section slides vertically in ways in front of a stationary chalkboard are widely used. A number of examples of such installations can be seen in the photographs of lecture room interiors in this chapter. Installations of this type are available from commercial sources. Individual chalkboard sections are usually mounted in aluminum frames and the boards are usually of standard height (3½ to 4 feet) and range in width up to about 15 feet. The larger widths flex perceptibly and sometimes annoyingly in use. Two or three narrow systems side by side are therefore preferable to a single installation that is too wide. However, the amount of flexing depends on the type of board installed. Slate is, of course, more rigid than other chalkboard materials in current favor though it weighs more for the same length.

Narrow boards can be raised and lowered quite satisfactorily by hand if they are properly counterbalanced. Wide boards are more apt to bind at the edges and hence are usually power operated. Their greater inertia also requires that they be mechanized.

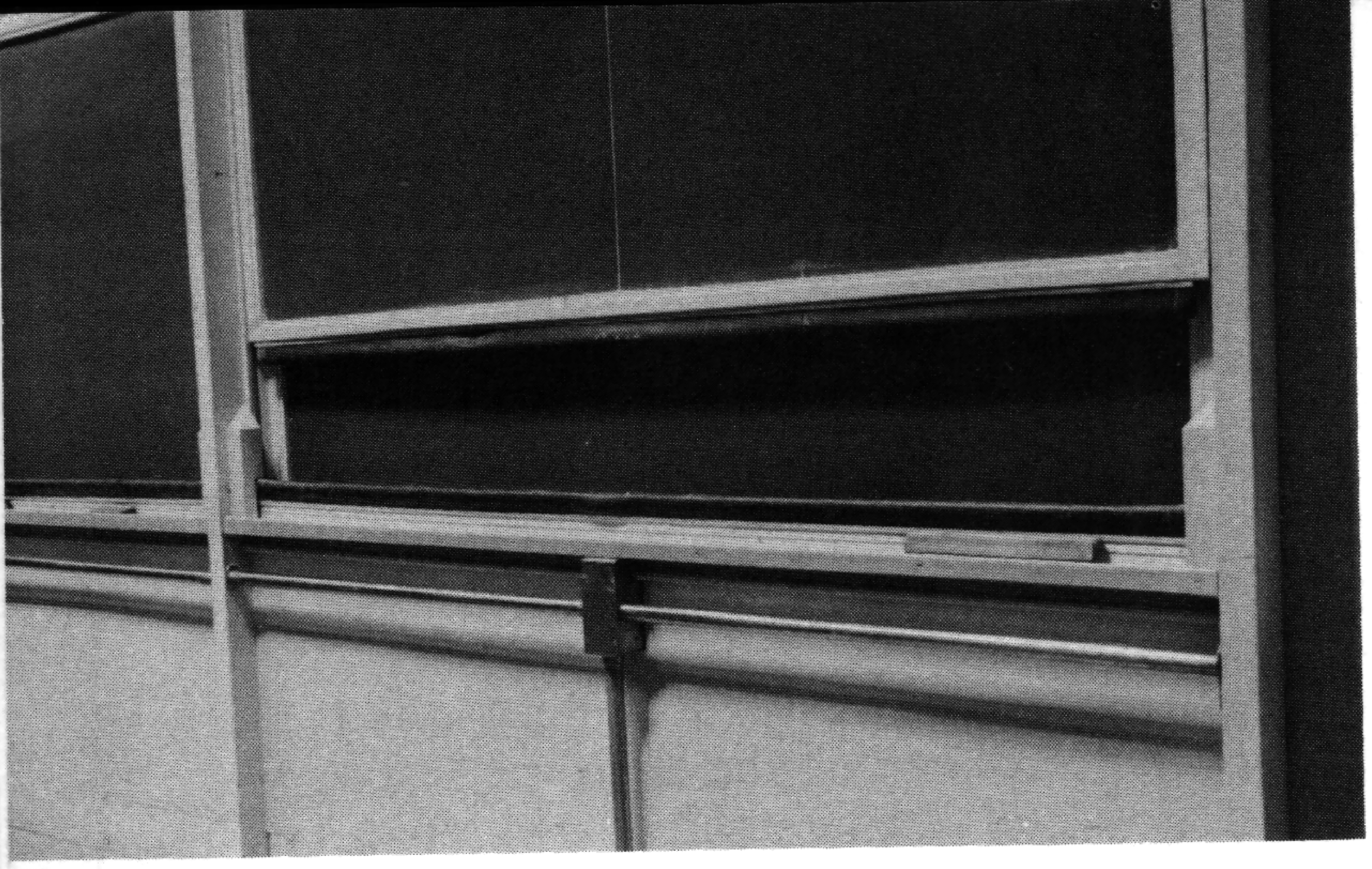


Figure 17. Movable chalkboards in Burr Hall, Harvard. Switch which controls motion of chalkboard is actuated by rotating long horizontal tube beneath chalktray. Wire, sheathed in rubber above chalktray, operates microswitch to stop motion if hand gets in the way.

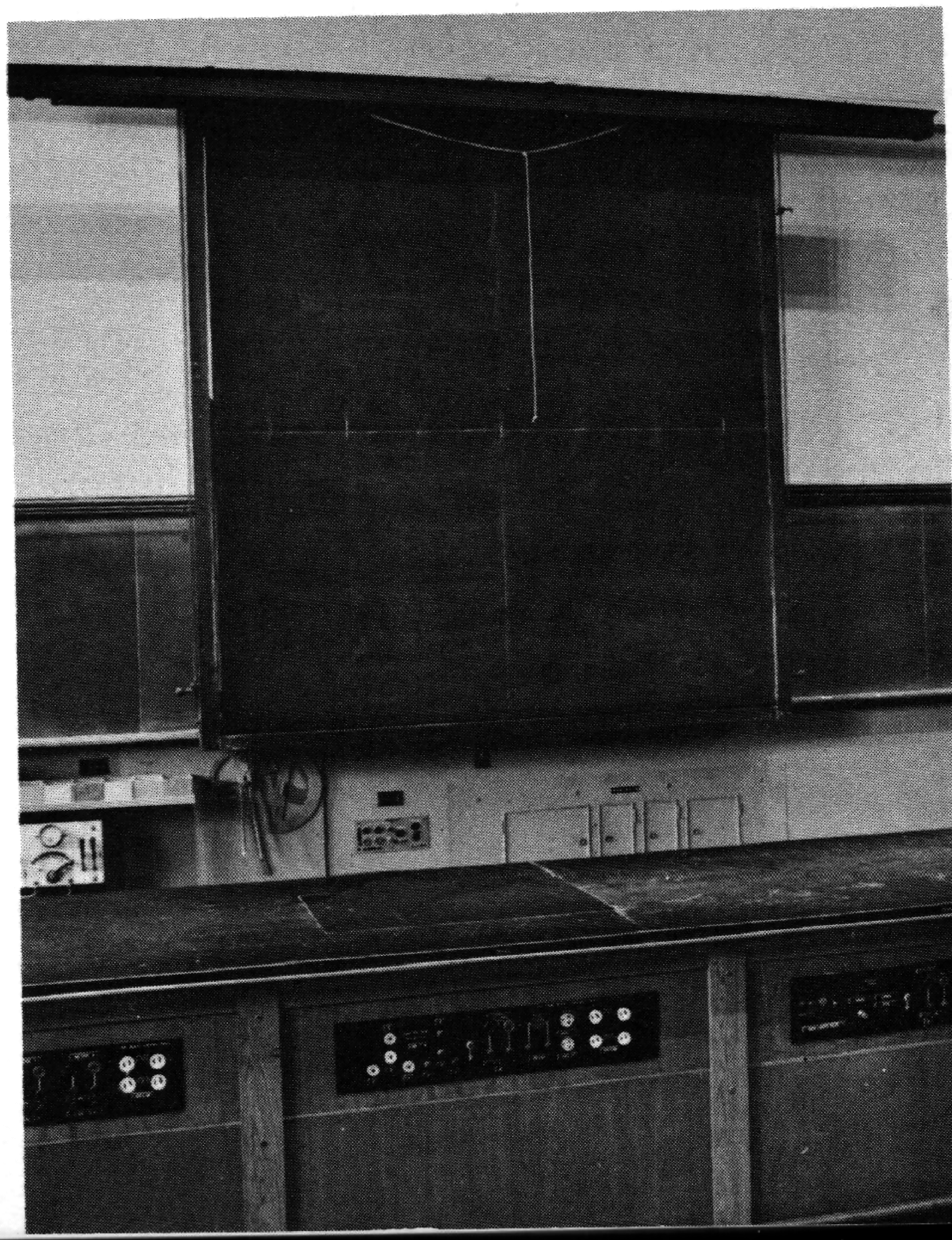
Electric motors are usually used for this purpose. Switches for controlling the motion of the boards are usually placed in the frame at one or both sides of the board. A more convenient device to actuate the switch consists of a long tube mounted beneath and parallel to the chalk tray in such a manner that the board can be made to move up or down by simply rotating the tube on its axis either one way or the other. One can then control the board readily from any position along its length without having to go to a switch. Figure 17 shows such an installation beneath the chalkboards in Burr Hall at Harvard. The figure also shows a safety measure which has been installed to avoid crushed fingers. A taut cable runs through the rubber sheath above the chalk tray and is connected to microswitches at each end. Either a downward or a sideways motion of the cable will operate the switch and stop the motion of the chalkboard. If one's hand is in the way, an additional rubber cylinder on the bottom of the movable chalkboard will push his hand against the cable and stop the board in sufficient time.

Circuit arrangements for movable chalkboard systems are usually designed to employ two simple pushbutton switches—one for moving the board upward and the other for moving it down. The board is automatically stopped by means of limit switches at each end of its path.

The principal criticism of such multiple chalkboard systems is that they rattle and flex when written upon. A number of instructors have reported that they find it desirable to hold one hand against the board as they write. The boards rattle because considerable play is necessary between the movable frame and the vertical channel to avoid binding. It is interesting to note that some older systems work more freely and yet rattle less than most recent installations, probably because the earlier systems were more carefully designed. For example, each of the 7-foot movable sections installed years ago in the physics lecture room at California Institute of Technology (about 1920) can be moved easily by hand and without binding by taking hold of the board at any point along its length. Small ball-bearing wheels are mounted at both the top and the bottom of each end of each movable frame and roll with but little play on tracks fabricated from cold rolled steel bars.

(2) Chalkboards which slide horizontally: Several new lecture rooms make use of aux-

Figure 18. Flexible continuous-belt chalkboard used in physics lecture halls, Princeton University.



iliary chalkboards which roll sideways in front of the stationary board. Such systems can be installed where there is insufficient head room for a vertical system, as at Pomona College where a low catwalk runs along the front of the lecture room. (See Figure 2). The two movable boards at Pomona are supported on rollers and move quite freely, with a minimum of play. Such horizontal systems are much simpler to construct and are less likely to get out of order than vertical systems. However, when the movable board is rolled sidewise it covers part of the stationary board and hence, a smaller fraction of the total area may be left exposed at any one time than with a vertical system.

(3) The roller-type chalkboard: Roller-type chalkboards are installed in two physics lecture rooms at Princeton University. A continuous flexible black chalkboard cloth, 8 feet wide by about 18 feet long, is supported by a roller at the top of a wooden frame and is kept taut by a weighted idler roller at the bottom (Figure 18). A flat board is mounted inside the frame to provide backing for writing on the cloth. A hand crank for advancing the cloth is located at the bottom of the frame, one on each side, and turns the upper roller by way of a chain drive. The entire system is supported from a rail in such a manner that it can be rolled sideways to any position at the front of the room. The surface of the Princeton chalkboard has good writing and erasing characteristics. In spite of the fact that a long fixed chalkboard is also available in the lecture rooms, we understand that some instructors at Princeton use the flexible chalkboards almost exclusively. A British firm manufactures the roller-type chalkboard in a variety of sizes. (Welson and Garden, Ltd., 17–21 Newtown St., Kilsyth, Nr., Glasgow.)

(4) Modifications: A very large single section of movable chalkboard is installed in the lecture room used jointly by the physics and chemistry departments at the University of Maryland. It is 15 feet wide by 12 feet high and dwarfs the two fixed sections of conventional 4-foot chalkboards which are mounted on each side of it (Figure 19). To write upon the upper portion of the movable board, it can be lowered into a recess behind the chalk tray. The long tall chalkboard in the Technische Hochschule at Zurich is similarly mounted.

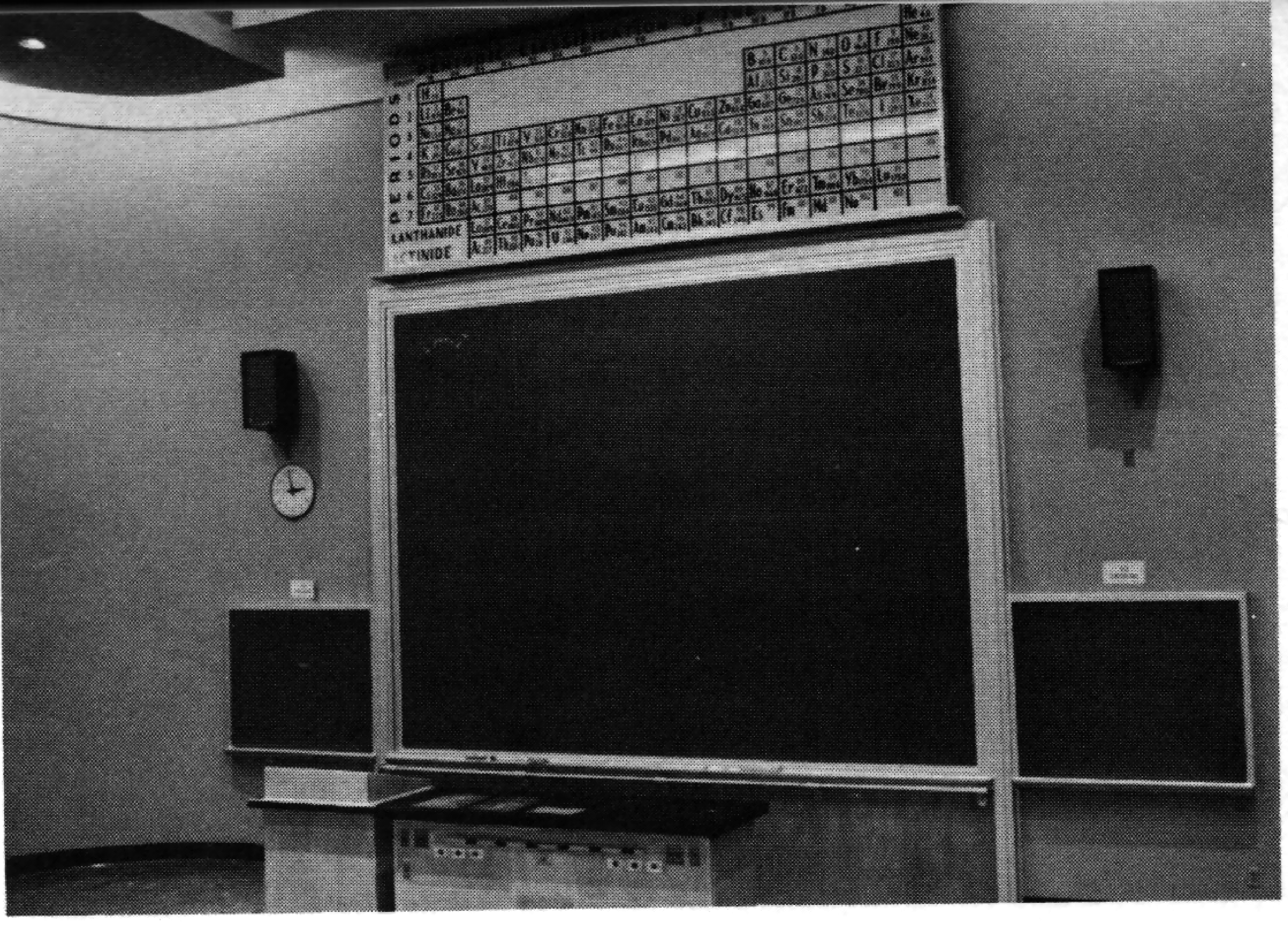


Figure 19. Large, single-section, movable chalkboard in the Physics-Chemistry Lecture Hall, University of Maryland. Chassis at left of lecture table is used to light up individual elements in the chart above the chalkboard.

The chalkboard system in the Karl Taylor Compton Lecture Hall at the Massachusetts Institute of Technology extends from the floor almost to the ceiling (Figure 6). Three movable sections can be moved vertically by hydraulic cylinders which are mounted at the top of the stationary chalkboard.

The pair of center chalkboards in the lecture room at the University of Florida are mounted on heavy doors which can be rolled sideways, as barn doors. The doors open into the demonstration apparatus storeroom behind the chalkboard (Figure 5).

Classrooms and lecture rooms at the new Air Force Academy make extensive use of "barn door" type of chalkboards. These are tall massive chalkboards which extend to the floor. They are mounted in pairs and can be rolled sideways one in front of the other. Figure 11 shows such an installation in one of the lecture rooms at the Air Force Academy, and Figure 14 in Chapter 7 shows similar chalkboards in a laboratory at the Academy.

Projection Facilities

A variety of optical projection facilities are used in physics demonstration lectures. They include ordinary optical projectors for slides, moving picture projectors, film strip projectors, devices for shadow projection of apparatus, and a variety of other devices for demonstrations in optics. Projectors should be mounted on a substantial base, free of vibration. Even a small vibration cannot be tolerated because of optical magnification at the screen.

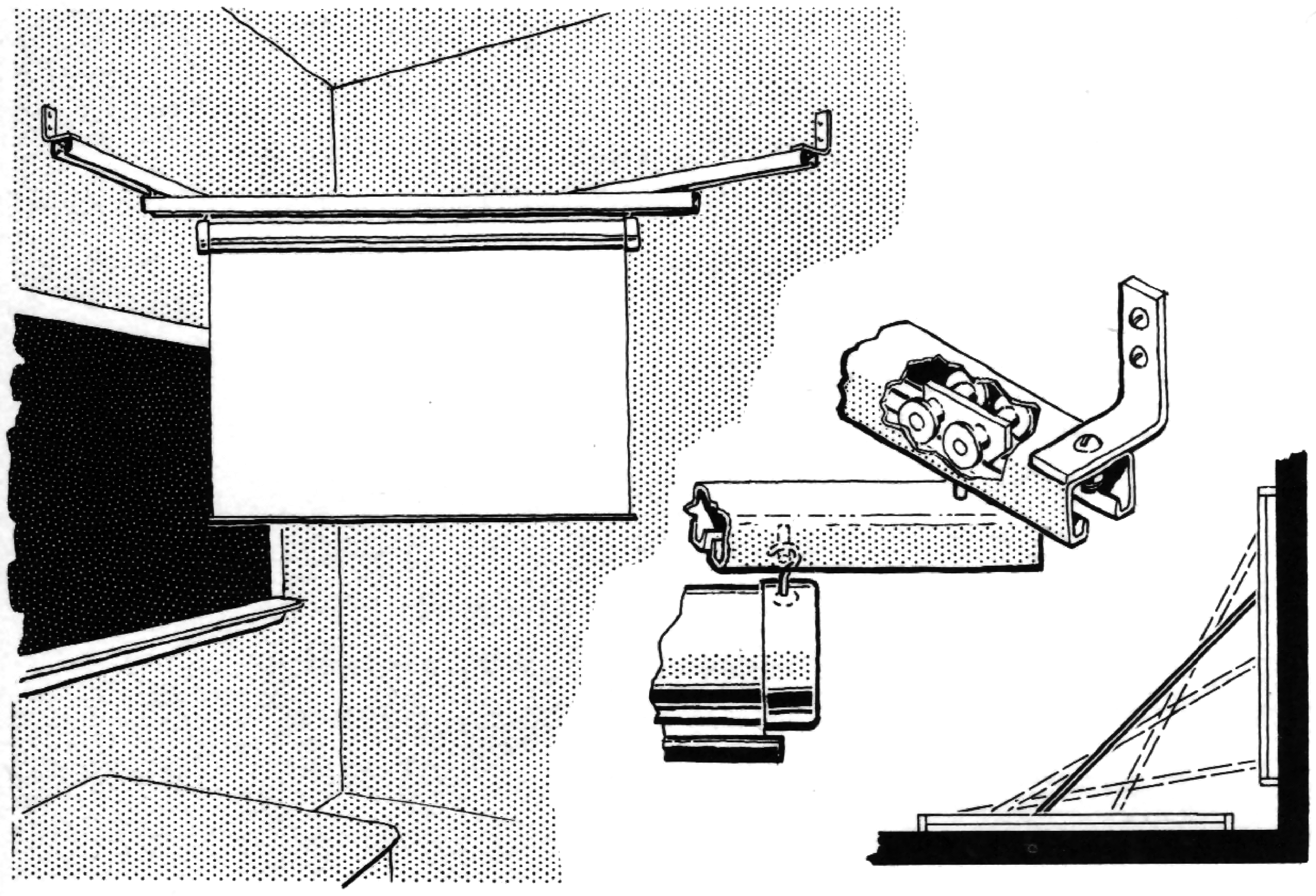
Carbon arcs are good light sources either as flood lights or for shadow projection. The series resistance required should be mounted inside the lecture table and a number of outlets for the arc proper should be placed at convenient intervals around the table. It is then much simpler to clamp the arc to any convenient support since the resistance will not need to be kept with it.

Screens. Many physicists find that a smooth, white, plastered wall is quite satisfactory for most projection purposes, and insist that as much clear wall area be provided as possible—across the front of the room and at the side. However, if an adequate wall surface is unavailable because the desired surface is otherwise taken up or because it is not at the desired angle for projection, projection screens can be installed. The screen should have a matte surface to produce diffuse rather than specular reflection. Beaded screens produce a brighter image than matte white screens for persons seated within an angle of about 20° from the normal to the screen. Beyond this, the brightness falls off rapidly as shown in Table III. Roll-type screens up to 10 feet or so in width can easily be controlled manually. Larger screens may have to be motor-driven. However, most of the powered screens we have seen are somewhat slow in operation, and some of them are noisy. If a powered screen is to be installed, the desired speed and maximum acceptable noise level should be clearly specified. One manufacturer quotes a screen speed of 16 feet per minute which seems to us to be unnecessarily slow. One advantage of a powered screen is that there is less chance of damage to the screen; some persons are careless in raising and lowering a manually operated screen.

Table III. Effect of Viewing Angle on Brightness of Beaded and Matte Screens

Viewing Angle (Degrees)	Brightness Ratio (Beaded Screen : Matte Screen)
0	3:1
10	2:1
20	1:1
30	4:5
45	3:5

Figure 20. Detail drawings showing method of supporting a screen on tracks in the corner of a lecture room so the screen can be oriented as desired.



Roll-type screens are frequently supported in one or both front corners of the lecture hall in such a manner that they can be turned to face in different directions. This can be accomplished by supporting the two ends of the screen housing on tracks mounted respectively on the two walls as suggested by Figure 20. The orientation of the screen can be adjusted manually by means of a simple set of cords and pulleys.

Table IV. Relation of Projection Screen Size and Distance

(a) For 3¼ by 4 inches (Aperture, 2¾ by 3 inches) slides
(Courtesy, American Optical Co.)

Distance to Screen	Width of Image (Feet)						
(Feet)	Focal Length of Objective						
	6½-inch	8½-inch	10-inch	12-inch	16-inch	20-inch	24-inch
10	4.4	3.3	2.8	2.3	1.6		
20	9.0	6.8	5.8	4.8	3.5	2.8	2.2
30	13.6	10.3	8.8	7.3	5.4	4.3	3.5
40		13.8	11.8	9.8	7.3	5.8	4.8
60				14.8	11.0	8.8	7.2
80					14.8	11.8	9.8
100						14.8	12.3

(b) For Opaque Projector with Delineoscope 1000
(Courtesy American Optical Co.)

Distance to Screen	Width of Image (Feet-Inches)	
(Feet)	Focal Length	
	18-inch	22-inch
10	5	3–11
15	7–6	6–1
20	10–8	8–7
25		11–3

(c) For Overhead Projector with 10 by 10 inch Projection Stage
(Courtesy Bessler Visual Products Co., Inc.)

Distance to Screen	Width of Screen Image (for 14 inch focal length lens)
(Feet)	(Feet—Inches)
6	4–0
8	5–4
10	6–8
12	8–0
14	9–4

(d) For 16 mm. Moving Picture Projector
(Courtesy, Bell and Howell Mfg. Co.)

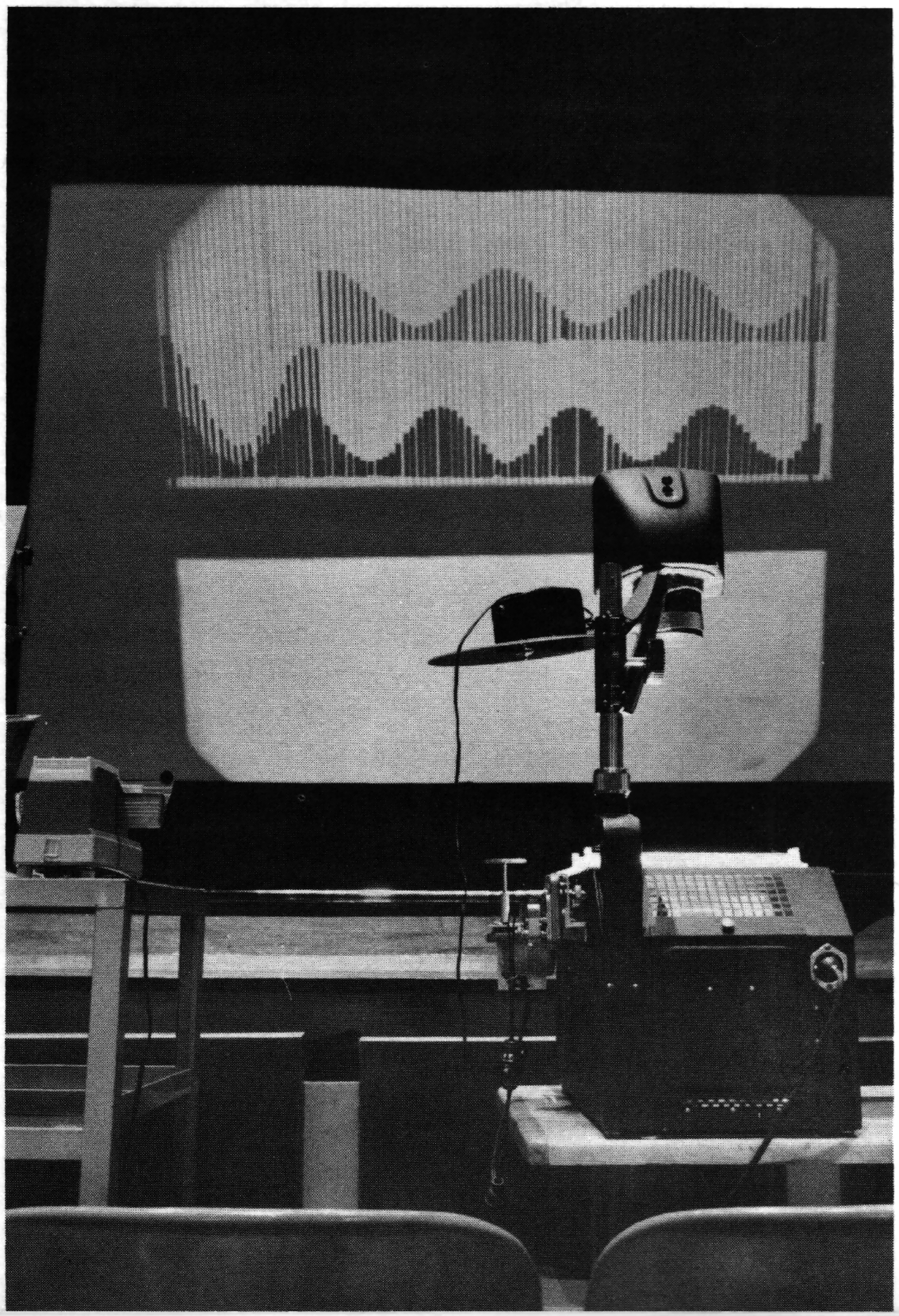
Distance to Screen	Width of Screen Image (for standard 2-inch focal length lens)
(Feet)	(Feet—Inches)
13	2–6
18	3–4
26	5–0
37	7–0
53	10–0
74	14–0

If a corner screen is used in a room with windows, the screen should be mounted on the window side of the room to shield the screen from direct window light.

Screens mounted in frames are occasionally used in place of roll-type screens in the front corners of the lecture room. They may be permanently mounted at the desired angle, or as in the Compton Lecture Hall at M.I.T. (Figure 6b), they may be supported by means of a vertical hinge at one side so they can be oriented as desired. Screens in frames are also sometimes mounted above the chalkboard at the front of the room and tipped forward so that images from a nearby projector will not be appreciably distorted.

The roll-type screen in the lecture room at Pomona is supported from a trolley beneath the catwalk which extends across the front of the room (Figure 2). The support point is pivoted so that the screen can face in any direction as well as be moved to any position along the front of the room.

Figure 21. Overhead projector used to project the shadow of a model to show the addition of waves, presented by Walter Eppenstein at the 1960 Summer Meeting of the American Association of Physics Teachers held at Oberlin.



The screen size required for various focal length projectors is given as a function of distance from projector to screen in Table IV. The width of the screen should be approximately equal to ⅙ the distance to the last row of seats.

PROJECTION FROM LECTURE TABLE. Most physics instructors prefer to handle their own slides and otherwise to manipulate the optical equipment used in their demonstrations, and to do so from the lecture table or from other tables in the front of the room. Overhead projectors are particularly convenient to use in conjunction with a screen (tilted to minimize distortion) above the chalkboard at the front of the room. Such projectors have great versatility for they can also be used for the shadow projection of various physical demonstrations. Figure 21 shows an overhead projector used to project the shadow of a model for demonstrating the superposition of waves.

An overhead writing projector is used almost to the exclusion of the chalkboard for classes in elementary physics held in the 400-seat physics lecture room at Cornell University. Such projectors are equipped with a wide roll of cellophane film upon which one can write with a grease pencil, draw diagrams, or work problems. Material can also be prepared on the film in advance. This technique also makes it unnecessary for the instructor to turn his back on his audience. To be sure, the amount of material that can appear on the screen at any one time is definitely limited. However, it is a simple matter to roll back the film to any earlier point in the lecture.

Conventional slide and opaque projectors placed on the lecture table are usually used with a screen on the side wall. The orientation of the screen is normally a compromise between good visibility and minimum distortion of the image. Shadow projection on the side wall is particularly effective, for students can then see the device being demonstrated as well as the projected shadow. Another advantage of side-wall projection is that the screen need not be raised whenever the chalkboard is used; screen and chalkboard are both ready for use at all times.

Since the lecture table is so near the front of the room, a better location for a projector is on an auxiliary table closer to the students. The center aisle in the lecture room at Pomona College described earlier (Figure 2), is made purposely wide so that a table can be set at any distance for various projection purposes. Convenient electrical outlets are mounted in the risers at the edge of the aisle to operate projectors and other equipment. In other lecture rooms, a fixed table is frequently substituted for two or three of the seats in one of the rows. Figure 22 shows such an auxiliary table in the new lecture room at Worcester Polytechnic Institute. In addition to the ac line, several free lines and a shielded cable run from this table to the electrical panel on the lecture table to provide greater versatility in setting up demonstrations. The table has a top 3 by 4 feet—a size suggested by the experience of the staff with a smaller table similarly located in their former lecture room.

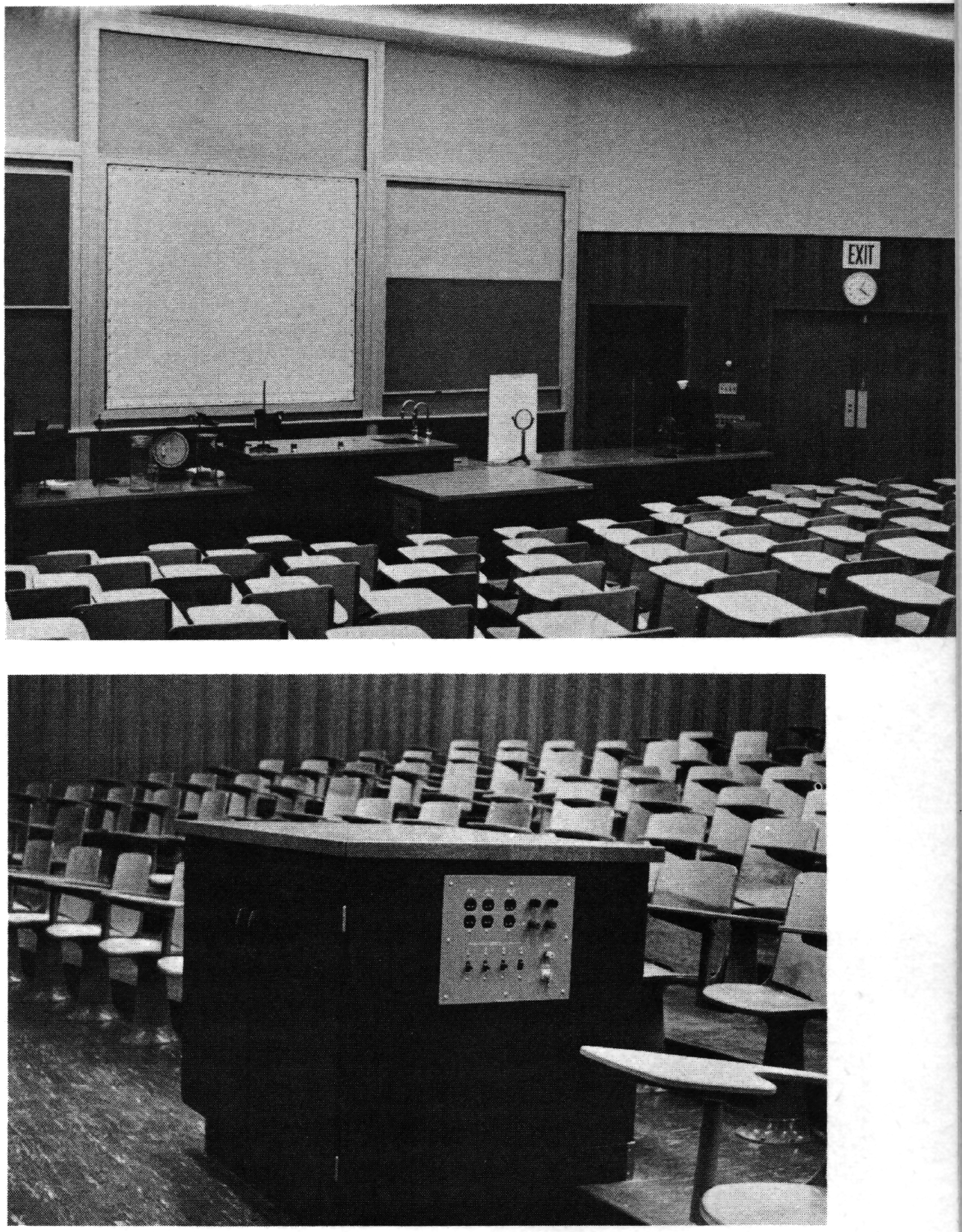


Figure 22. Lecture room, Olin Hall of Physics, Worcester Polytechnic Institute (Chapter 4, Figure 15), and close-up of auxiliary projection table.

Projection from Rear of Lecture Room. There are advantages in projecting onto the center screen from the rear of the lecture room, particularly when movies are to be shown. The center screen provides a less distorted image and better viewing for most persons in the room. In addition, the visual distraction sometimes caused by the operation of a projector at the front of the room is eliminated. This is particularly to be desired on more formal occasions when prepared lectures require the services of an operator. A table that is permanently installed for this purpose should have, in addition to several convenience ac outlets, at least one pair of free lines and a shielded cable running to the lecture table, a cable connected to a loud speaker in the front of the room for sound movies, and dc voltage for an arc. The free lines can be used by the lecturer to signal the operator or for the automatic operation of a projector—advancing slides automatically or turning a moving picture projector on and off. Such lines can be installed much more economically when the building is being built than at a later date.

A booth for housing projection equipment in the rear of the room is regarded as a luxury by most physics staffs. It uses up desirable space and, of course, adds to the building cost. A booth does have certain advantages, however. The noise caused by the operation of moving picture projectors is muffled. Furthermore, projection equipment can more readily be protected from tampering. We found that booths are occasionally installed in physics lecture rooms, however, principally in lecture halls that are extensively used for public occasions or in those relatively few places where the physics instructor makes extensive use of an assistant throughout the lecture period.

A booth is required by the building code in most communities for the showing of inflammable 35-mm film. However, essentially all educational films are available in the nonflammable 16-mm size for which a booth is not required.

Back Projection. A translucent glass screen is installed behind the movable chalkboard in each of the lecture rooms at the University of Tennessee. The screen can be used for back projection from the adjacent store room—either for the projection of slides or for shadow projection. Images can also be projected on the rear of the screen from a projector located at one end of the lecture table. Projection then takes place through an open door and by reflection from a large mirror set at the proper angle about 10 feet behind the screen. One of the projectors is conveniently mounted within the lecture table with its axis vertical so that slides (or small objects for shadow projection) can be placed on a glass plate in the plane of the top of the table.

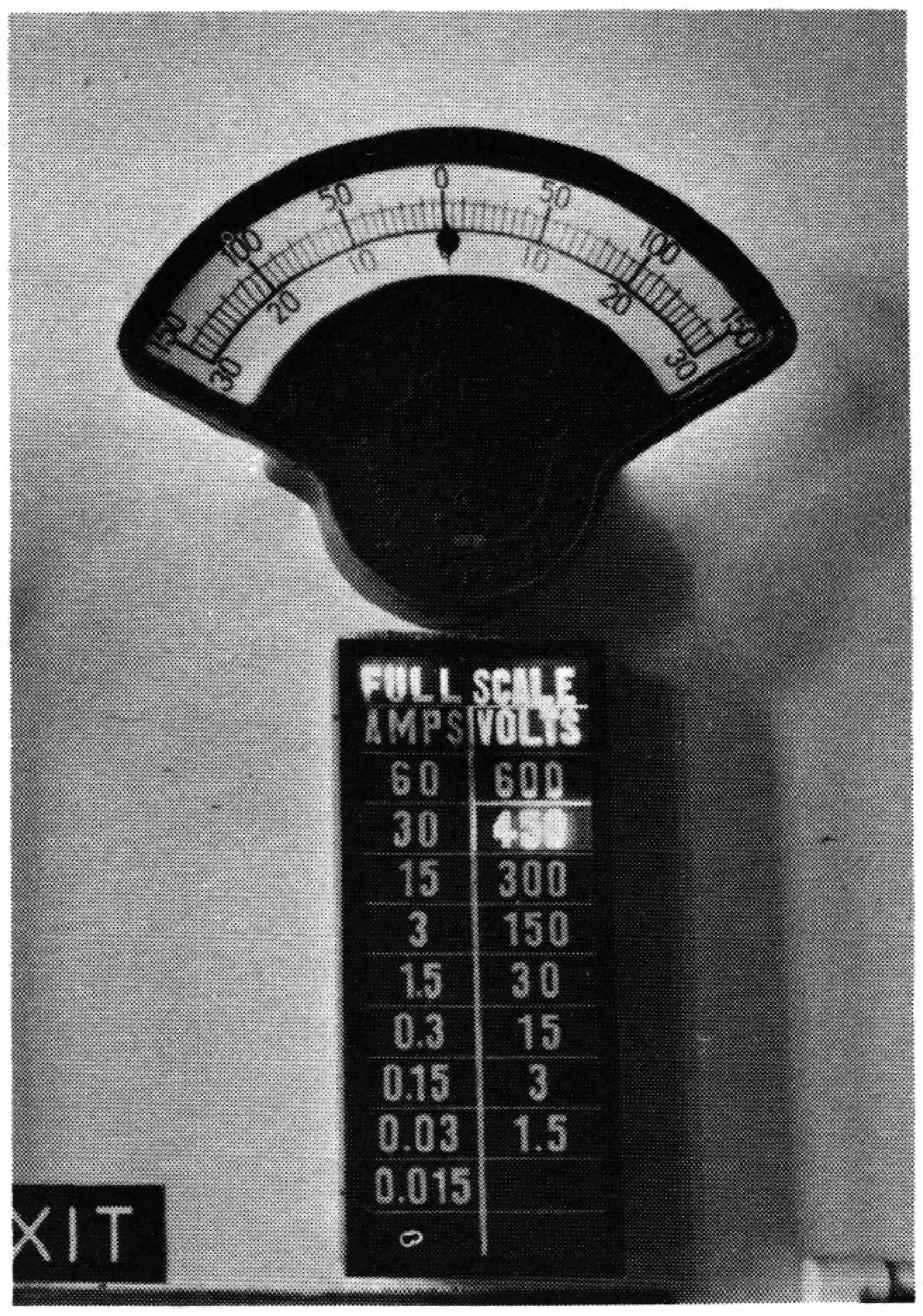
Wall-Mounted Instruments and Apparatus

Permanently Mounted Instruments. An electric clock is the instrument most frequently seen in a physics lecture room. It not only keeps instructors and students aware of the passage of time but is frequently used for timing demonstrations. At two institutions we saw a clock mounted flush with the top of the lecture table, apparently primarily for the instructor's benefit. Certain other instruments such as a timer (1 second per revolution), galvanometer and scale, voltmeter, ammeter, and loud speaker are also occasionally permanently mounted on the wall of a lecture room. Leads from these instruments are connected to terminals at the lecture table where an appropriate assortment of shunts and series resistances is provided for the meters.

Each of the wall meters in the physics lecture room at Princeton University has mounted a device beneath it which lights up to indicate how the instrument is being used —to show (1) whether it is connected as an ammeter or as a voltmeter and (2) the range of the instrument. Figure 23 shows one of the instruments, apparently connected as a 450-volt voltmeter.

Some instructors prefer to use table-mounted meters provided with over-size

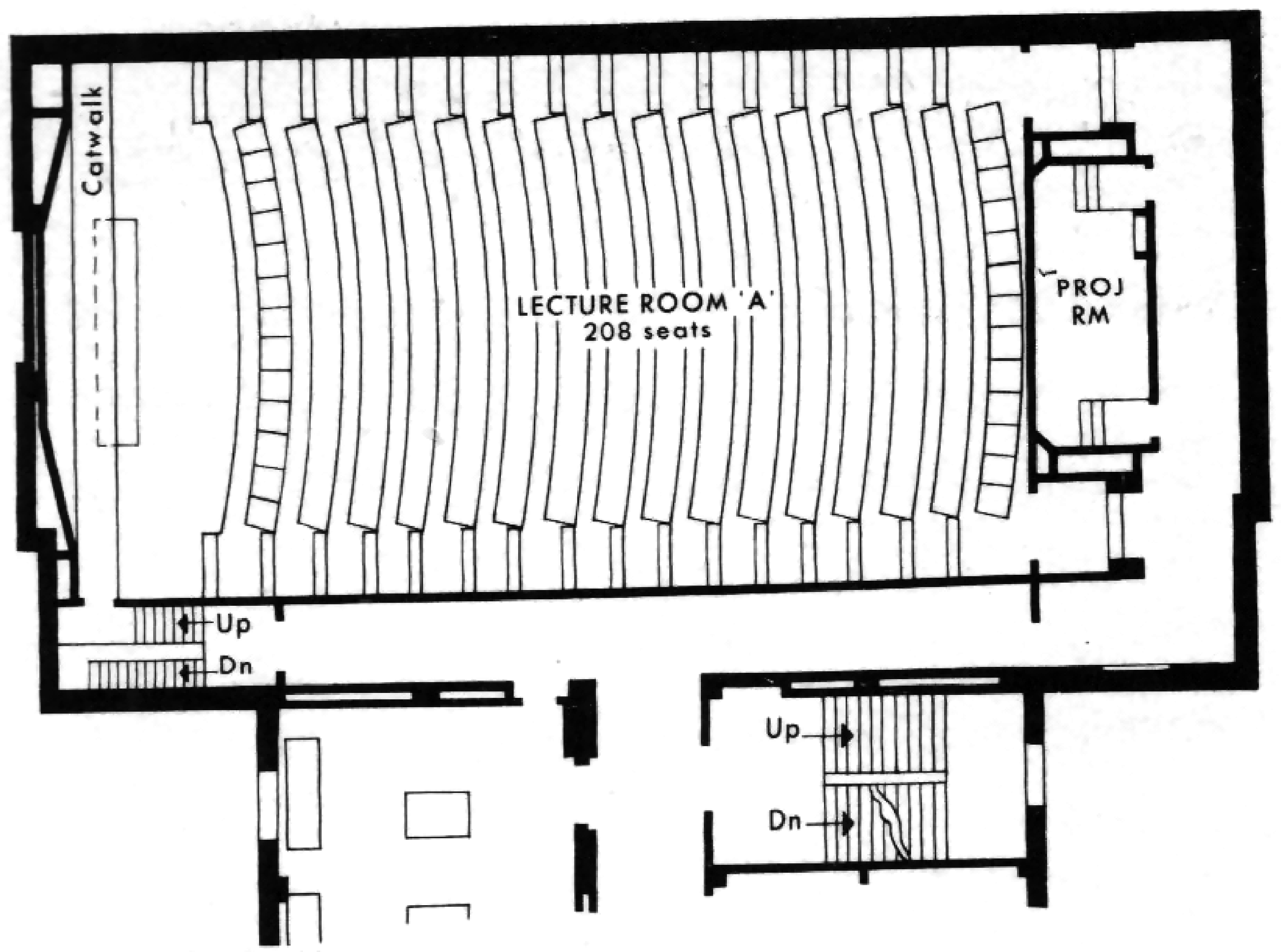
Figure 23. Wall-mounted meter in the physics lecture room, Princeton University. Note individual indicator lights showing whether instrument is connected as an ammeter or a voltmeter and the range of the instrument.



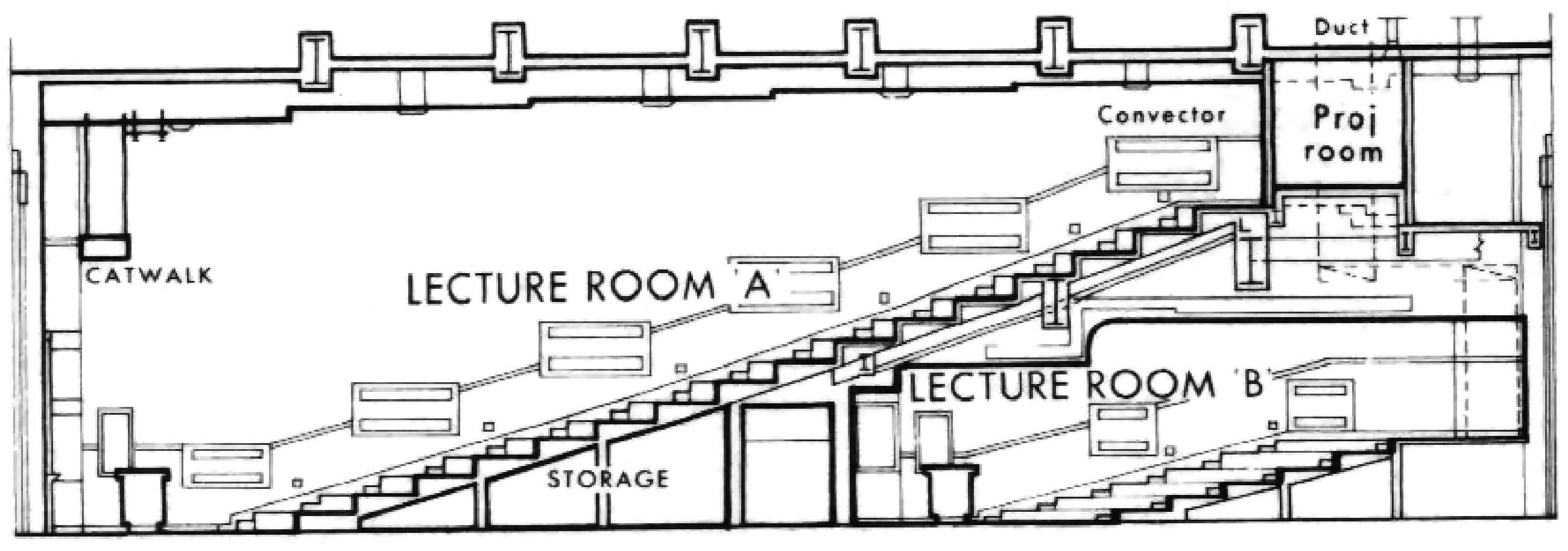
scales in their demonstration lectures instead of wall meters. The leads are not then behind the table and out of the students' sight. Others prefer to use projection meters—small meters with transparent scales which can be inserted into ordinary slide projectors. It is apparently for these reasons that very few new buildings are equipped with permanently mounted ammeters and voltmeters though a galvanometer and scale combination is still occasionally installed. At one institution the galvanometer is mounted behind the front wall and its deflection is projected onto a translucent scale in the wall.

One finds other miscellaneous devices permanently mounted in physics lecture rooms. A metal plate has been mounted behind the plastered wall in one lecture room to reflect electromagnetic waves. In another, a metal plate is attached to a side wall in such a fashion that a spring scale shows the force which a ladder exerts when leaning against it. A demonstration slide rule is frequently mounted in a lecture room though more frequently in a classroom. Other devices such as apparatus for the measurement of the velocity of light and the gravitational constant are also occasionally seen permanently mounted in lecture rooms.

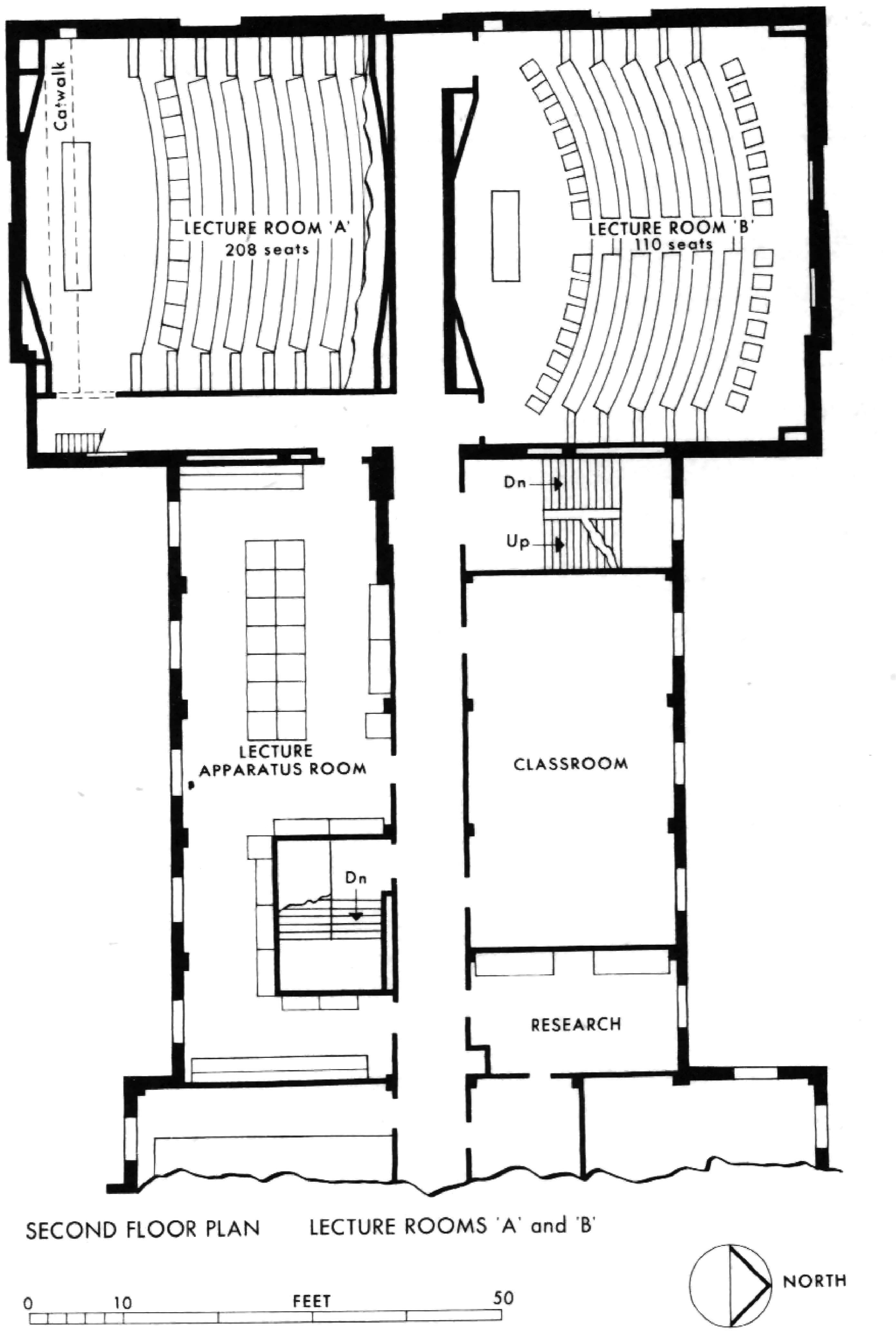
DEVICES FOR SUPPORTING APPARATUS. A physics instructor has many occasions for hanging different pieces of apparatus for demonstration purposes. This is frequently accomplished by the use of one or more hooks in the ceiling or in the walls of the lecture room or by using a steel beam above the lecture table. The minimum load specification for ceiling hooks should be 500 pounds. Pulleys at the ceiling are convenient for raising apparatus or charts. Occasional openings in the ceiling are also found to be convenient. Steel or aluminum channels mounted on or flush with the walls or ceiling provide great versatility. A catwalk from which experiments can be performed or apparatus suspended is installed near the ceiling at the front of a number of lecture rooms. Figure 24 shows the catwalk in the



THIRD FLOOR PLAN



SECTION THROUGH LECTURE ROOMS 'A' and 'B'



SECOND FLOOR PLAN LECTURE ROOMS 'A' and 'B'

Figure 24a. Floor plan of the lecture rooms in the new Physics Building at the University of Virginia (Chapter 4, Figure 13). Photograph is shown on following page.

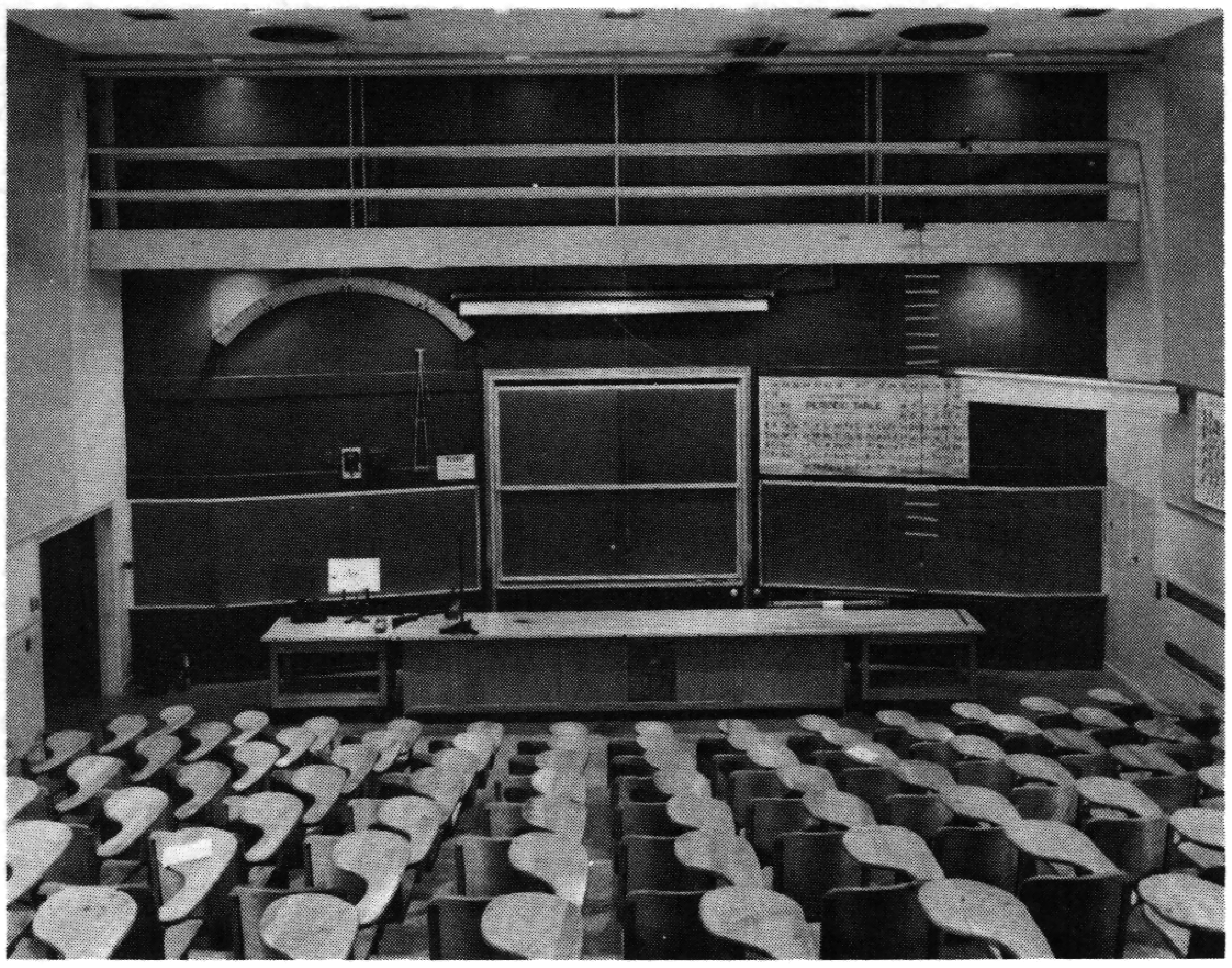


Figure 24b. View of the large lecture room, Physics Building, University of Virginia, showing catwalk and permanently mounted instruments.

200-seat physics lecture room at the University of Virginia. It is reached by a short flight of stairs from a second floor passageway. The catwalk in the lecture room at Pomona College (Figure 2) is reached by a door from the hall on the first floor. A small balcony which serves the same purpose at the University of Texas is hidden behind the acoustical reflector (Figure 7). It is reached by a door from the mezzanine in the preparation area. A monorail which passes through this doorway serves a two-fold purpose. Various devices can be suspended from it and heavy objects can readily be moved between the apparatus storeroom and the lecture room by means of a movable hoist. The catwalk in the lecture room at Stanford University shown in Figure 1d is reached by a spiral stairs located in the apparatus storeroom.

Metal channels which can be installed along the top of a chalkboard together with matching hooks provided with spring clips are useful for hanging light objects. Commercial channels of this sort are available with cork inserts for thumb tacks.

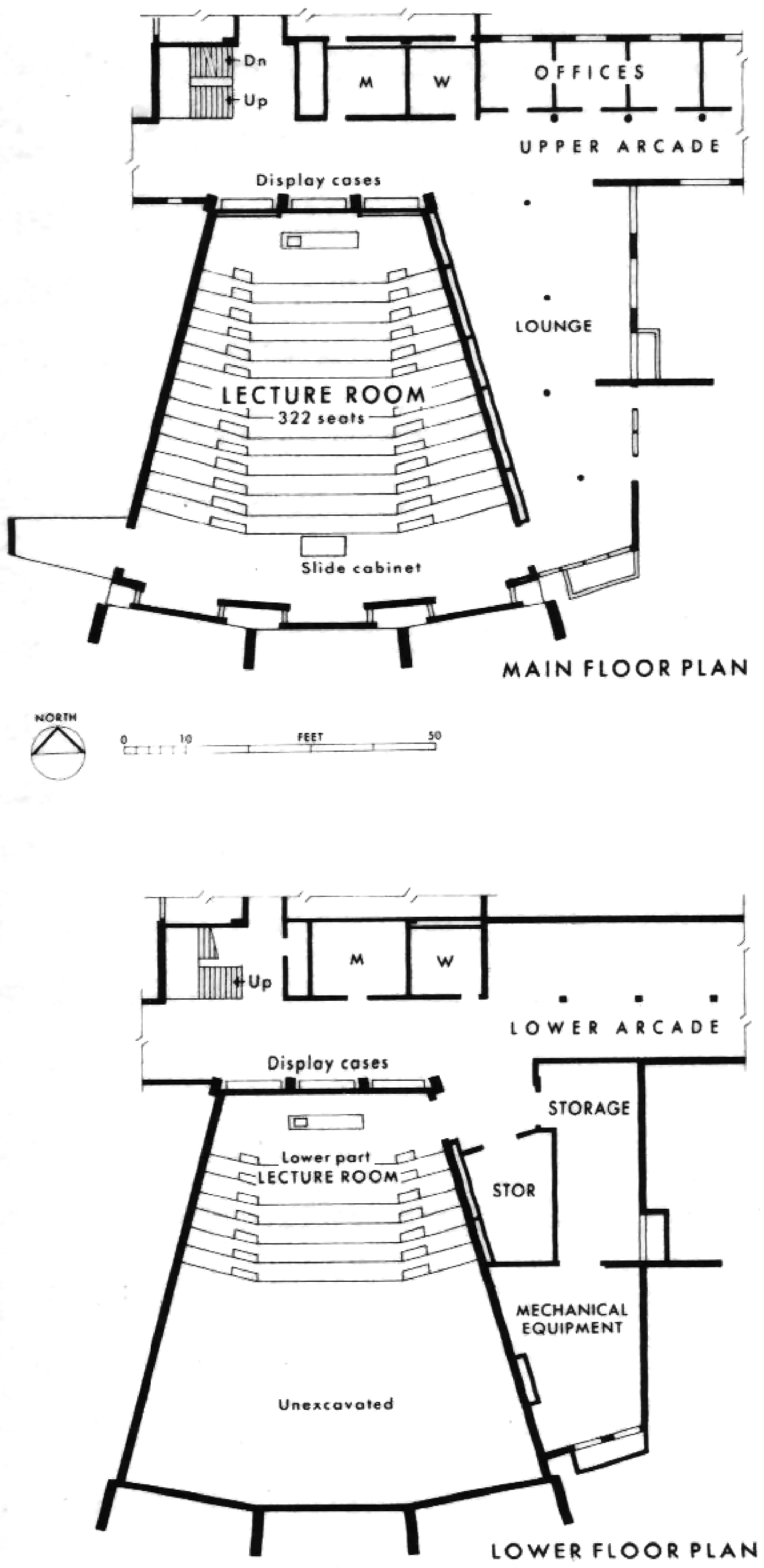
A tackboard is occasionally found on the wall of a lecture room. It is principally used for supporting charts or notices, although for the latter purpose a bulletin board located in the corridor far enough from the lecture room entrance for student conversation to be inaudible is preferable.

The Lecture Table

The lecture table in the physics lecture room is designed to facilitate the presentation of demonstrations. Outlets for the electrical and mechanical utilities that are required should be installed in the table in as convenient a manner as possible.

LECTURE TABLE LAYOUTS. Most physics lecture rooms have fixed lecture tables, 15 to 20 feet in length. Apparatus is brought into the lecture room on carts and transferred to the lecture table, or on rolling tables which usually match the width and height of the lecture table and may be clamped to it to increase its effective length.

Recently, to conserve time in setting up demonstrations in the lecture room itself, a number of schools have installed relatively small fixed tables in the lecture room—tables not much larger than necessary to house the desired utilities. The fixed tables are then used in conjunction with much larger rolling tables which match them in height and width. The apparatus to be demonstrated is set up on the rolling table in the preparation area outside the lecture room and is ready for use after rolling the table into the lecture room following a few on-the-spot adjustments. The table can be locked in place by clamping it to the fixed table, by clamping the wheels, or by lowering feet which raise the wheels from the floor. Clamping the wheels alone may not be sufficient for wheels that swivel. Power is supplied to ac and dc outlets on the movable table by flexible cables which can be connected to matching outlets on the fixed lecture table, or to outlets in the preparation room for setting up demonstrations. Figure 25 shows such a system in use at Colorado State University. Here the fixed table is only 3 by 3 by 3


Dn
Up
M
W
OFFICES
UPPER ARCADE
Display cases
LOUNGE
LECTURE ROOM
322 seats
Slide cabinet
MAIN FLOOR PLAN
NORTH
0
10
FEET
30
Up
M
W
LOWER ARCADE
Display cases
STORAGE
Lower part
LECTURE ROOM
STOR
MECHANICAL EQUIPMENT
Unexcavated
LOWER FLOOR PLAN

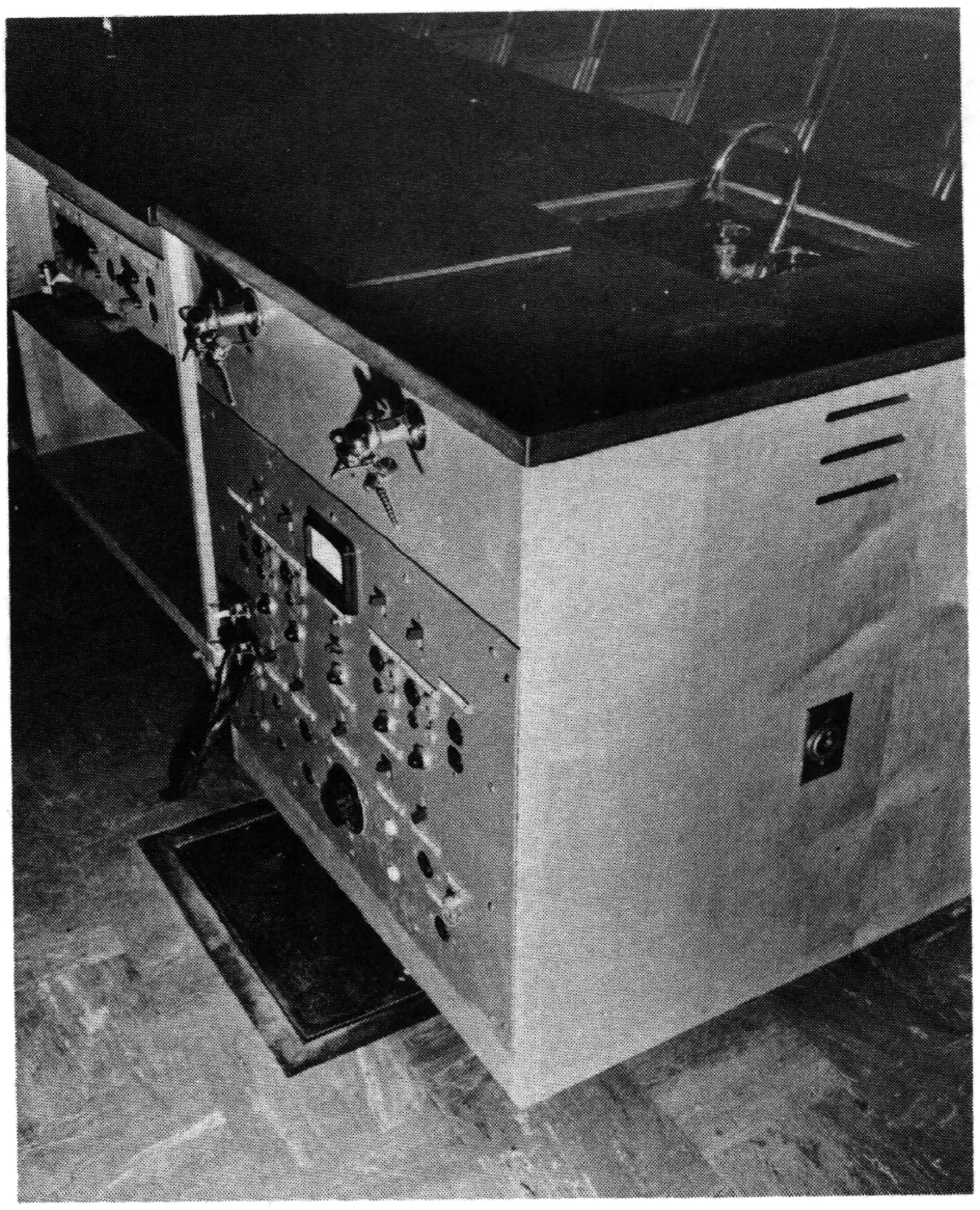
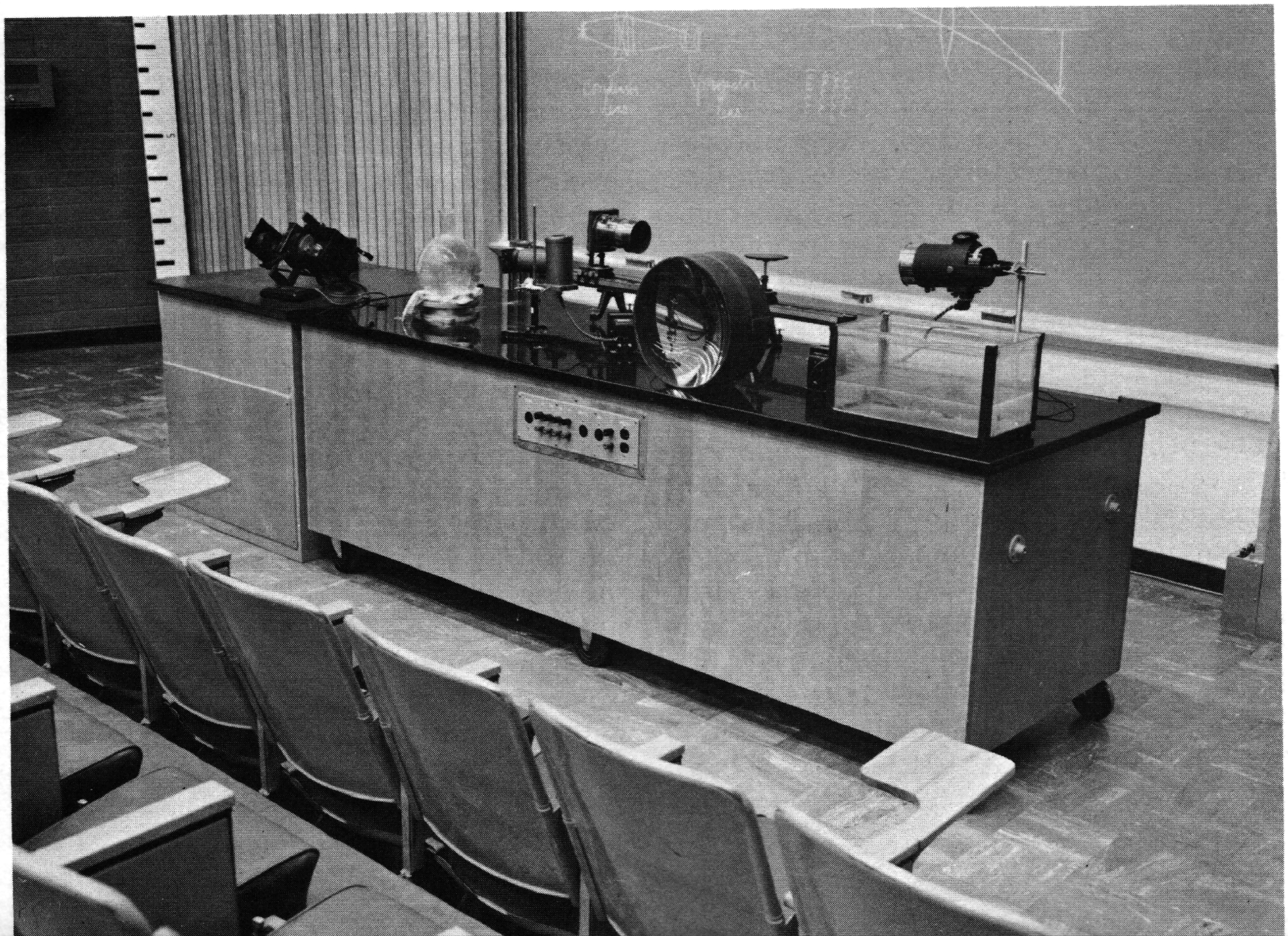


Figure 25. Floor plan, lecture room in the new Physics-Engineering Building, Colorado State University (Chapter 4, Figure 18). Photograph at right shows service outlets installed in small fixed table and flexible cable which supply electric service to movable lecture demonstration table (shown in photograph below).



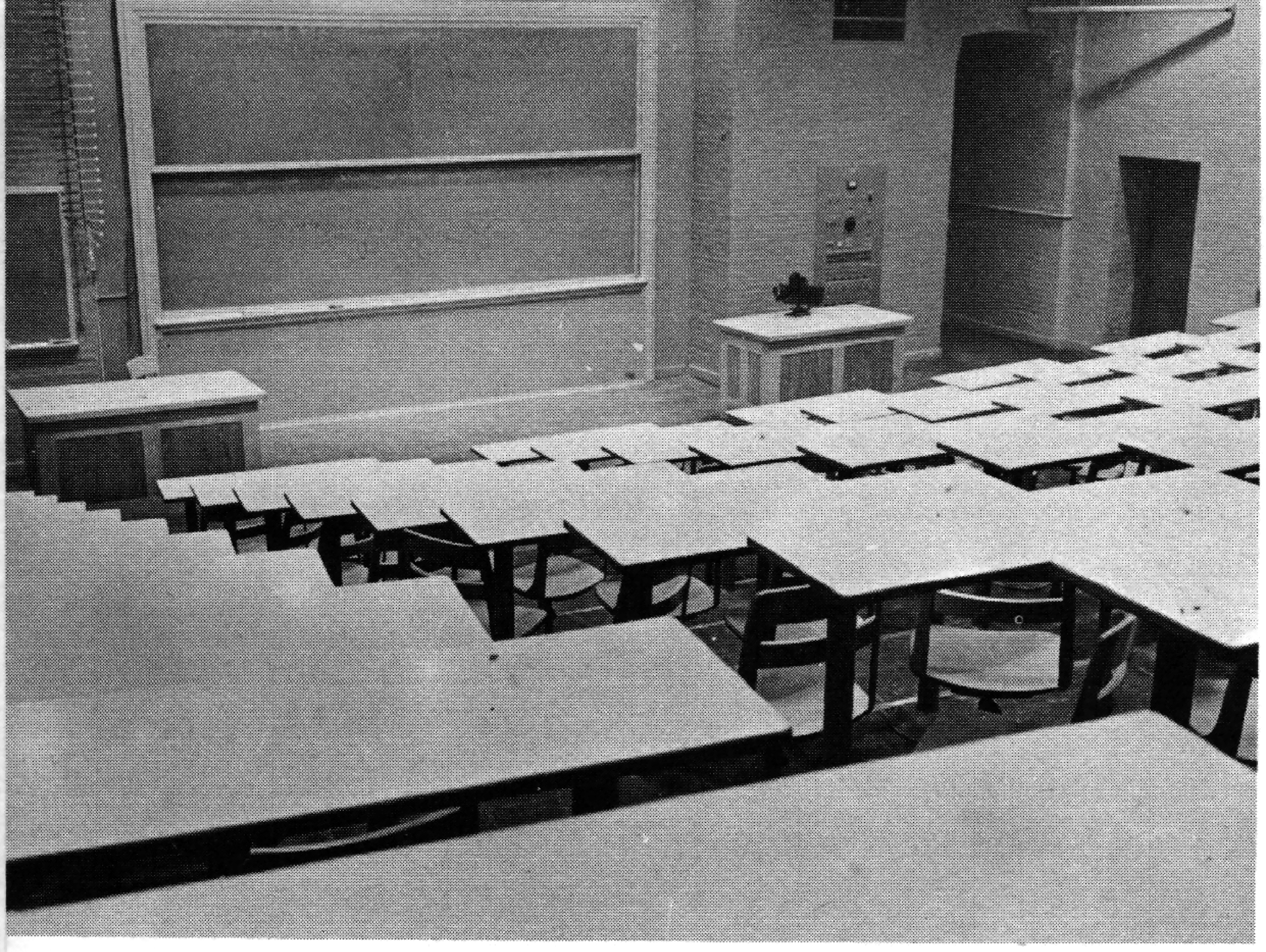


Figure 26. Fixed tables are used in the remodelled physics lecture room at Dartmouth College. Each table provides a large writing area for two students.

feet and is placed well to one side of the center at the front of the lecture room. The movable table shown has the same width and height as the fixed table, and is 9 feet long. Five-foot and 7-foot movable tables are also used at Colorado. The 9-foot table has a pair of fixed wheels in the middle of the table and wheels that will swivel at each end, thereby making it possible to steer the table while either pushing or pulling it.

How long does it take to set up demonstrations in the lecture room itself? The physics staff at Colorado State University finds that it is possible to schedule classes at successive hours by setting up their demonstrations on these movable tables beforehand. They believe that the 10-minute interval between classes allows sufficient time for them to make most readjustments that may be required after the apparatus has been rolled into the lecture room. (Classes were scheduled consecutively until 4:00 PM the day we visited Colorado State University.) However, at some institutions where roll-in tables have been adopted, the short time interval between classes was found to be too short for the satisfactory last minute adjustments that are required. As a result lecture demonstration activity at these institutions has unfortunately been curtailed. Most physics instructors feel that the lecture room must be free for at least one hour prior to a demonstration lecture to allow final adjustments to be made. At Northwestern University, three hours are set aside for this purpose.

A curved theatrical screen that can be drawn in front of the lecture table is installed in the larger of the two physics lecture rooms at Stanford University, as shown in Figure 1. This makes it possible for a class to use the lecture room while apparatus is being set up on the lecture table for a subsequent lecture. A set of folding doors is similarly available to enclose the lecture table in the physics lecture room at Oberlin College.[8] A chalkboard is mounted on the face of each door to increase the usefulness of the room when the doors are closed.

Some departments find that two fixed tables with an open space between them provide greater versatility than a single table. Figure 26 shows such an installation in the recently remodelled 176-seat physics lecture room at Dartmouth College. Each of the fixed tables is 36 by 68 by 36 inches. The movable tables that are used have the same heighth and width as the fixed tables, and their lengths (34 inches each) are such that three of them just fill the space between the fixed tables.

Two much longer fixed tables (11 feet each), separated by about 3 feet, are installed in each of the lecture rooms at Stanford University (Figure 1). The space between the tables is closed with a shelf when a long continuous surface is required; or it can be left open to shorten the distance the instructor has to travel in going from one side of the table to the other. The space is also useful for certain apparatus which should be centered in the room and yet not placed on top of or in front of the table. A TV monitor appears in this space in the photographs of Figure 1.

TABLE CONSTRUCTION. Lecture tables should be sturdy in construction. They are invariably constructed of wood because of its non-magnetic properties and its low electrical and thermal conductivities. The tables have cabinets and drawers beneath the table top for frequently used tools and miscellaneous materials. An open shelf may be useful for devices like a vacuum pump. The table top must be particularly rugged and have an abrasion-resistant finish. It should be constructed of laminated wood or narrow strips of hardwood glued together so that its surface will remain flat and not warp. The top should be at least 1½ inches thick and have at least a 2½-inch, and preferably a 3-inch, overhang so that table clamps can be secured to it. Commercial tables are likely to be supplied without an adequate overhang unless the desired amount is definitely specified. If movable tables are to be used for demonstrations, they should be as sturdy in construction as the fixed tables and their tops should be equally rugged. Drawers and open shelves in movable tables are an added convenience. Cabinets with doors are usually omitted. Wheels should have rubber tires and be large enough (at least 4 and preferably 5 inches in diameter) so that they roll freely to minimize the disturbances to demonstration set-ups.

The color of the table top is important in making demonstrations stand out clearly. Most instructors find that a light color provides much better contrast for most demonstration apparatus than the black baked coating of certain commercial table tops. The clear finish of natural wood is frequently specified. A light linoleum or plastic surface is also good. Regardless of the color, the finish of the surface must be dull to avoid the annoyance of specular reflections.

Besides an adequate overhang for clamps and rods, lecture tables are frequently equipped with a number of flush metal inserts located in the top of the table. These are available commercially to take either tapered or threaded rods (⅜-inch rods, 16 threads to the inch). Tapered rods are quicker to set up, but they usually possess undesirable play since their tapers are not uniform. Threaded rods can be seated more securely. Inserts should be of such a type that they can be attached to the table so they will not loosen. Two recommended types and the methods of attaching them are described in Chapter 7. (See Figure 20 in Chapter 7.) When inserts are simply attached to the table with wood screws they loosen in time.

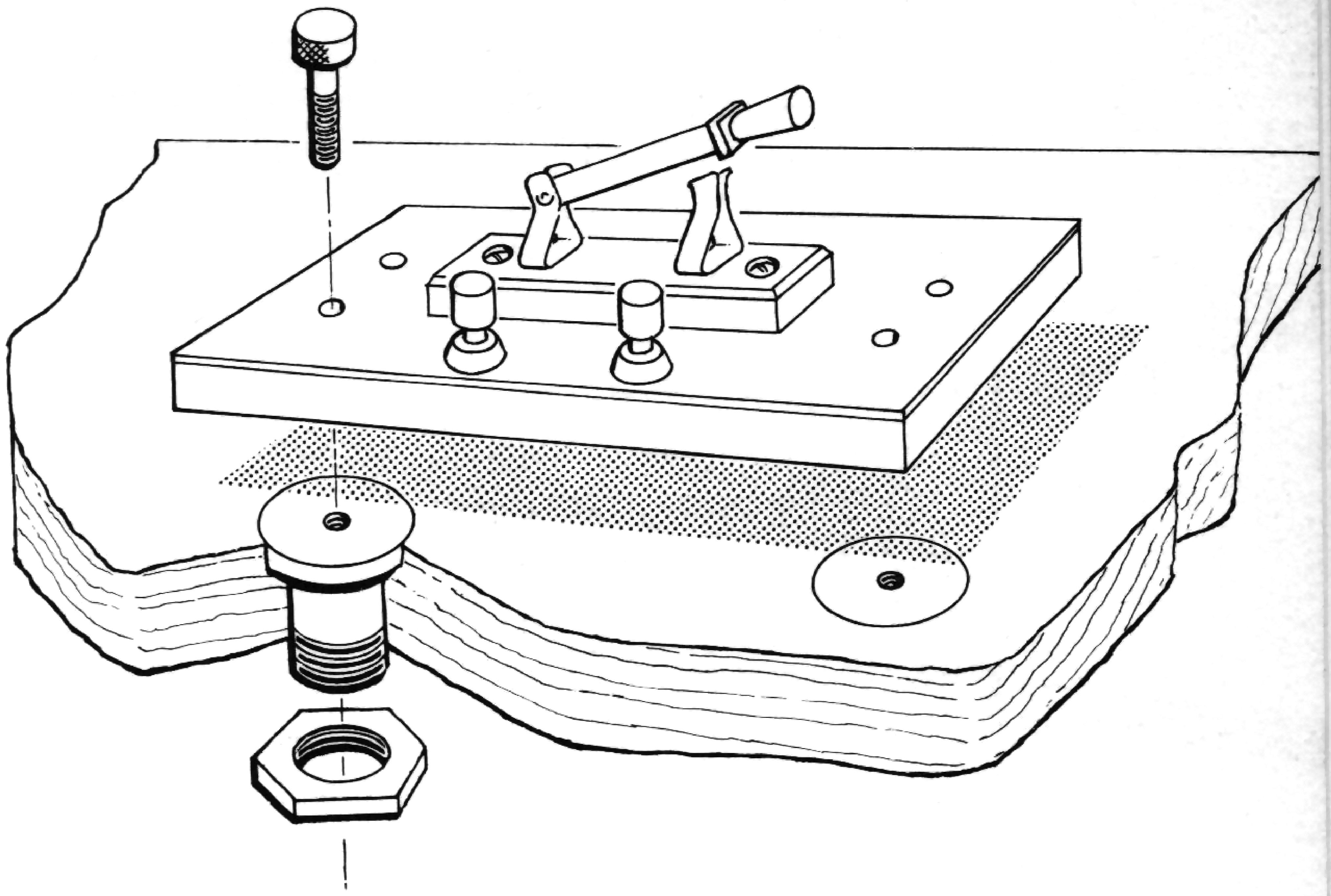


Figure 27. Cutaway drawing of lecture table top showing small devices mounted on block which is fastened to table top by screws that mate with metal inserts in table.

Smaller metal inserts are convenient for fastening small metal plates or blocks of wood to the lecture table. Various small parts such as electric switches and sockets can be mounted on such blocks, as sketched in Figure 27. The inserts are usually tapped to take ¼-inch screws with 20 threads to the inch. A number of such pairs of inserts are installed on the physics lecture tables at Harvard.

Rotating Stage

Rotating stages are widely used in theaters to change scenery rapidly. Classes could be scheduled every hour in a lecture room with

Table V. Frequency with which Various Services are Installed in Physics Lecture Tables

Service	Frequency of Installation			
	All	Most	Occasional	Rare
Sink with drain	X			
Cold water	X			
Hot water			X	
Distilled water				X
Steam				X
Gas	X			
Compressed air		X		
Vacuum				X
Free lines to central switchboard		X		
Free lines to preparation area			X	
Free lines to projection stand			X	
Coaxial lines to switchboard			X	
Coaxial lines to preparation area				X
60c ac outlets, 15 amps.	X			
60c ac outlets, 50 amps.			X	
60c ac 3-phase outlets (either 120 or 220 v.)		X		
120 v dc generator		X		
120 v dc generator and series resistance (for arc)			X	
Ground connection		X		
Microphone terminal (to amplifier)			X	
Terminals for wall-mounted loudspeakers			X	
Terminals for other wall-mounted instruments			X	

a rotating stage if it were equipped with two or more complete sets of demonstration facilities. Demonstrations could then be set up back stage and turned into position during the period between classes.

A rotating stage 34 feet in diameter is being planned for the proposed Physical Sciences Lecture Hall at the University of California in Berkeley, as shown in Figure 33 in Chapter 4.[9] Three chalkboards, each about 25 feet long, will be permanently mounted in a triangular pattern on the stage to divide the periphery of the stage into three sections. A lecture table with a complete set of utilities will be mounted in each one of the three areas. Flexible cables and pipes can be used for utilities since the platform needs to be rotated only 120° to bring any one of the demonstration areas into use. Two short tables will be permanently mounted in the lecture room—one at each side of the rotating platform—to extend its length and to provide additional services. Since the lecture room is to be used for both physics and chemistry, one of these fixed tables will have a down-draft hood for toxic fumes and the other will have a massive base on which delicate instruments can be mounted.

Each of the departments will have a store room and preparation area in the proposed building, and since there will be three complete lecture facilities mounted on the revolving platform, two hours, as a minimum, will always be available to set up demonstrations.

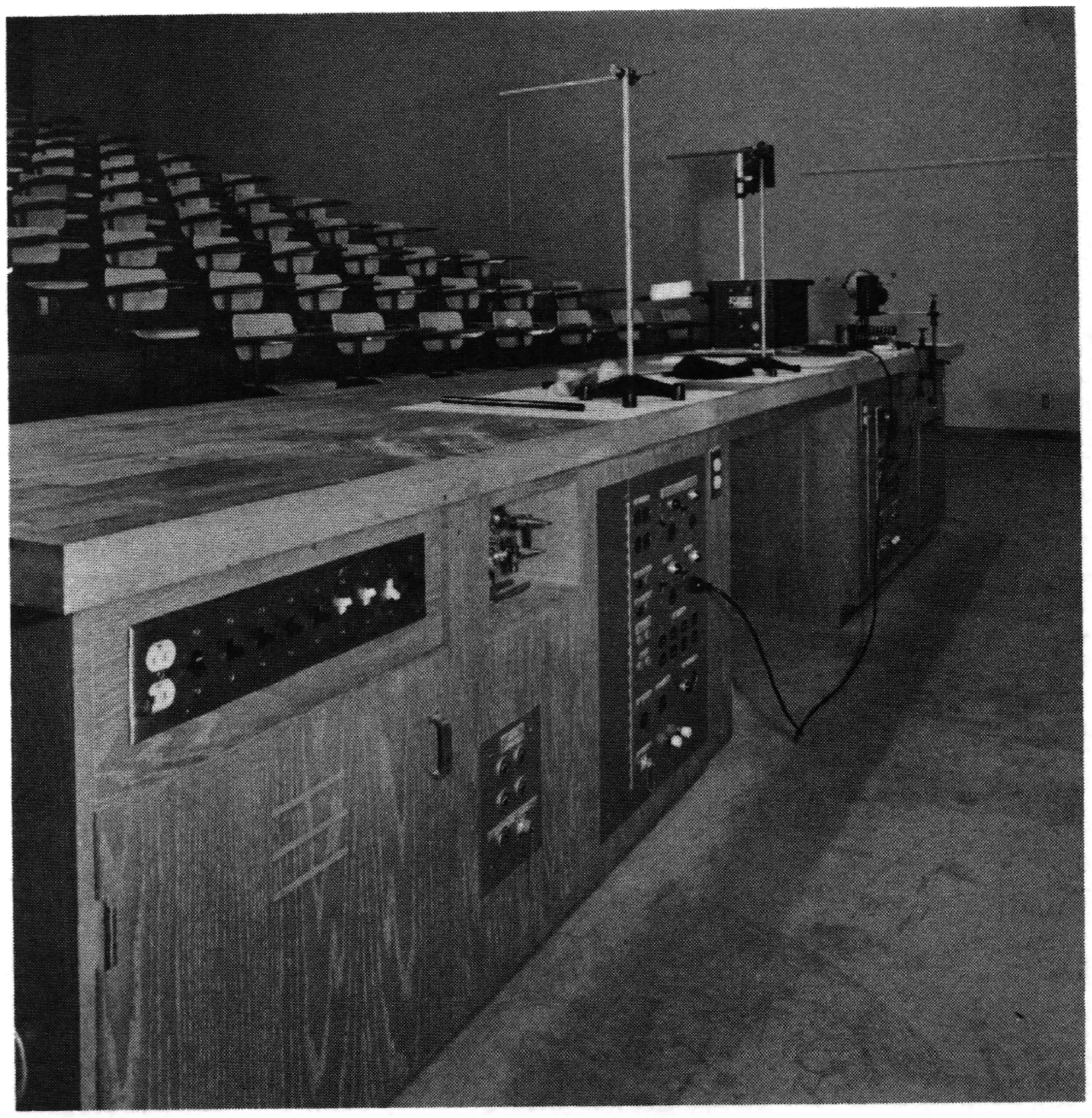
Services

Table V shows the approximate frequency with which the various electrical and mechanical services are made available in physics lecture rooms.

The sink is normally made of soapstone and set in the top near one end of the lecture table so that gooseneck faucets can be placed out of the way near the edge of the table. A cover which is flush with the top of the table is usually provided. Gooseneck faucets should be installed within the sink and on a pivot so they can be folded down beneath the cover when not in use. Faucets should be provided with nipples for hose connections.

Gas and air cocks are occasionally mounted on the top of the table and either near the end of the table or on the opposite side from the instructor. They should preferably be placed just below the overhanging top of the table on the instructor's side where they are more out of the way and still conveniently located for use. Thought should be given to the desirable spacing and orientation of these cocks so that hoses can readily be attached and used with a minimum of kinking, and so that the valve handles are easy to operate and yet cannot be accidentally turned. Kinking can be reduced by the use of a small hole in the table top adjacent to each stopcock. Accidental turning of the handle can be minimized by an adequate overhang on the instructor's side of the table, or by recessing the stopcocks as in the lecture table at Pomona College (Figure 28).

Figure 28a. Lecture table in the physics lecture room at Pomona College. Note duplicate panels for electric power and separate panel for room lights.



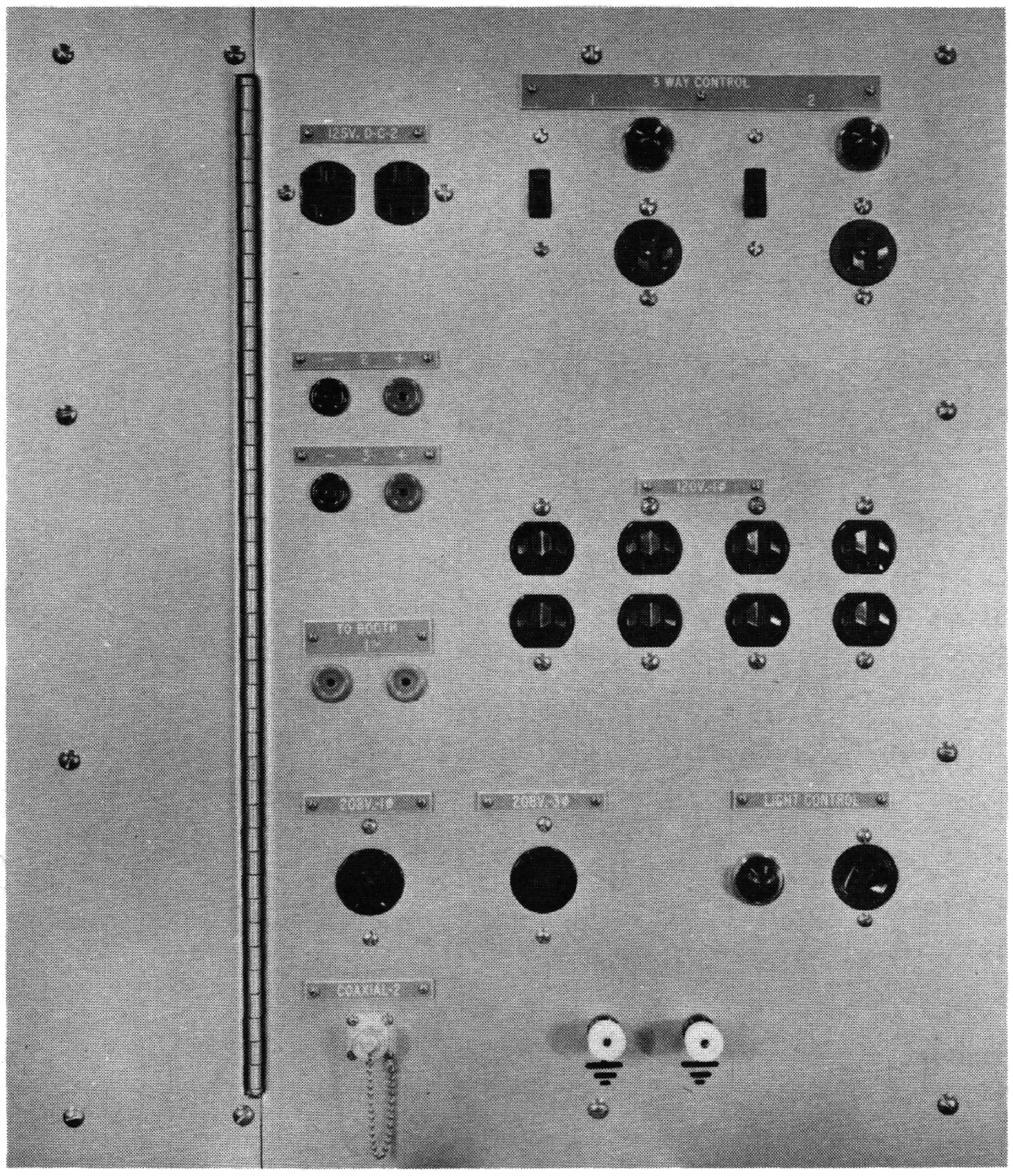


Figure 28b. One of the power panels, hinged for easy access.

Electric service outlets are usually grouped together on a special panel beneath the overhang on the instructor's side of the table, as shown for the Pomona College lecture table in Figure 28. To avoid confusion, room light controls should be mounted on a separate panel. The various remaining electrical services should be logically grouped on the power panel, with different types of outlets for different services: standard convenience outlets for 120-volt ac (with any high-current outlet specially marked or requiring a different plug); polarized outlets for dc; jacks for free lines to the central switchboard, if any; and special sockets or terminals for other devices and services. Some persons prefer binding posts to jacks. Therefore, for greater versatility all jacks should be paralleled with binding posts—posts which will take both spade lugs and banana plugs. All outlets should be clearly labeled. If the lecture table is long, one of these panels should be mounted near each end of the table. A number of additional ac convenience outlets are usually distributed generously around the table beneath the overhang, as well as at a number of other locations around the room. Bare binding posts and knife switches are hazardous and should not be a part of any permanent installation.

Circuit breakers are now largely being installed instead of fuses to protect both the ac and dc power lines. Those serving the power panel are sometimes mounted directly beneath the respective outlets on the lecture table panels or they may be mounted on a special panel in the preparation area. Circuit breakers for the lighting circuits may also be mounted on the lecture table panel but are more often located with other lighting circuit breakers in a panel in an adjacent corridor.

A unique type of lecture table is used in two lecture rooms at Louisiana State University, (Figure 29). The staff likes the arrangement so well that a similar table will be installed in another lecture room which will be in the new wing currently being added to the physics building. The table is 15 feet long and of normal height, but only 15 inches wide. It might more appropriately be called a service rail, for its principal use is to provide the utilities required for the demonstrations which are largely carried out on movable tables placed in front of the fixed table. A 10-inch square sink with hot and cold water is near one end of the rail. Gas and air outlets are near the front edge at each end. The electrical services are conveniently arranged on two panels mounted flush with the top of the table. Duplicate panels are located in the preparation room. When the movable tables are not required, more usable floor space is available in front of the lecture table for carrying out certain demonstrations than if a conventional table had been installed.

A rail for utilities is used exclusively in Professor R. W. Pohl's lecture room at the University of Gottingen, Germany. By placing the rail (Figure 30) directly in front of the first row of seats, an open area is left between it and the front wall for movable tables and portable optical equipment, with no fixed furniture to interfere. A chalkboard extends about half way across the front wall. The rest of the wall is free for the optical projection of the demonstration experiments for which Professor Pohl is noted.

Provision for Student Books and Clothing

Extra books and outer wraps are a nuisance in the lecture room when there are not free seats on which to store them. Built-in coat racks or sturdy metal coat racks with shelves for books should be installed in the rear of all lecture rooms. A separate coatroom may be provided if it has two doors—a definite entrance and exit, as at Swarthmore (Figure 3). As reported by one school, a coatroom which has only one door is never used.

All seats that are installed in lecture rooms and classrooms should have shelves beneath them for storing extra books.

Multi-Use of Lecture Room

There are several devices that enable a physics lecture room to be used for other purposes and still not interfere with its use for physics. In one scheme, already described, a flexible curtain or a folding partition can be drawn across the room in front of the lecture table so that the room can be used for a lecture not requiring demonstration facilities at the same time that demonstration apparatus is being set up on the lecture table. A roll-type screen can be mounted ahead of the partition and pulled down when projection facilities are required. A chalkboard can also be installed so that it can be lowered ahead of the screen and secured to the floor, as is done in Burr Hall B at Harvard.[3]

A lecture room is frequently designed for both physics and chemistry. Many of the facilities already described for physics will be used for chemistry. A larger and deeper sink

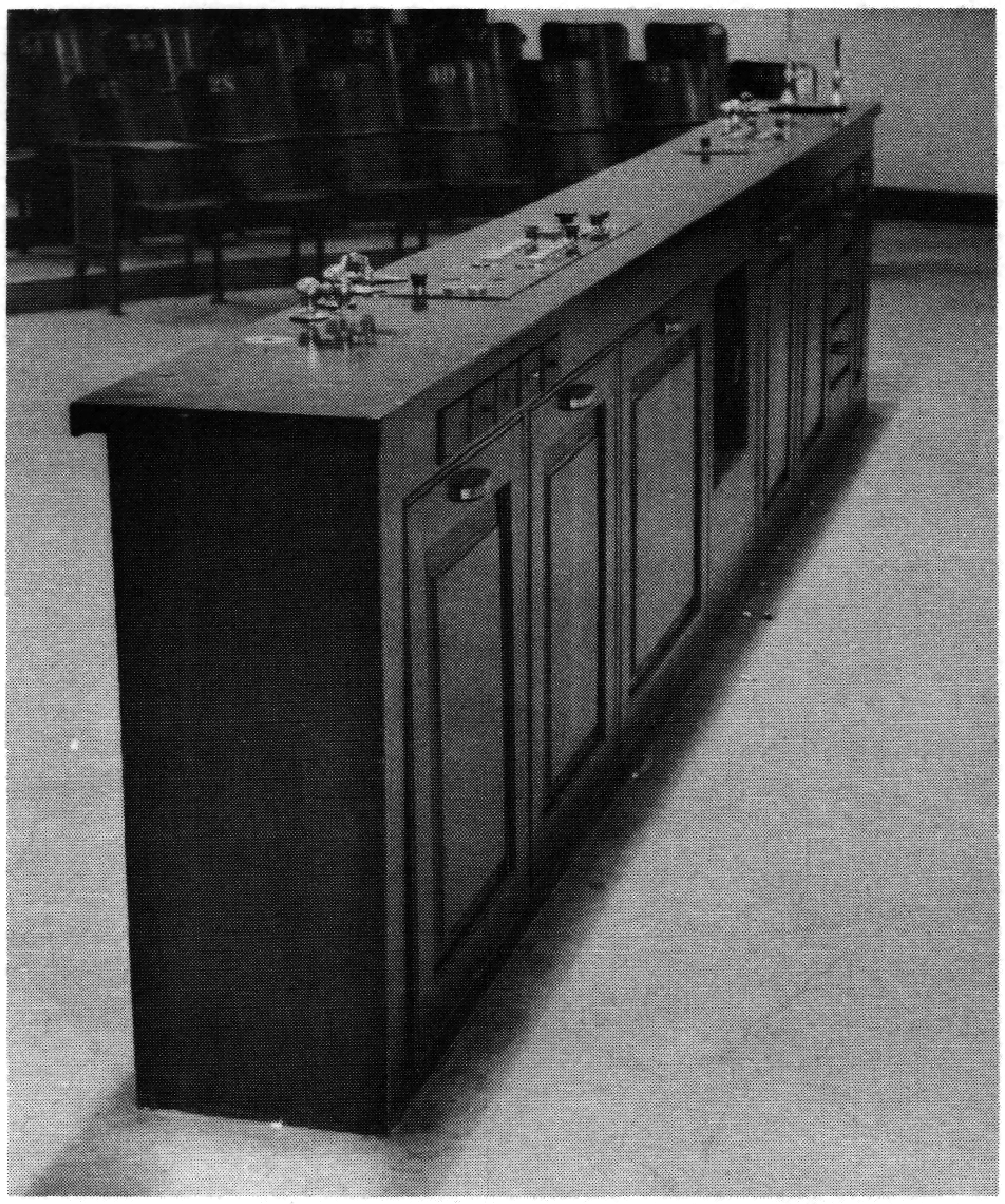
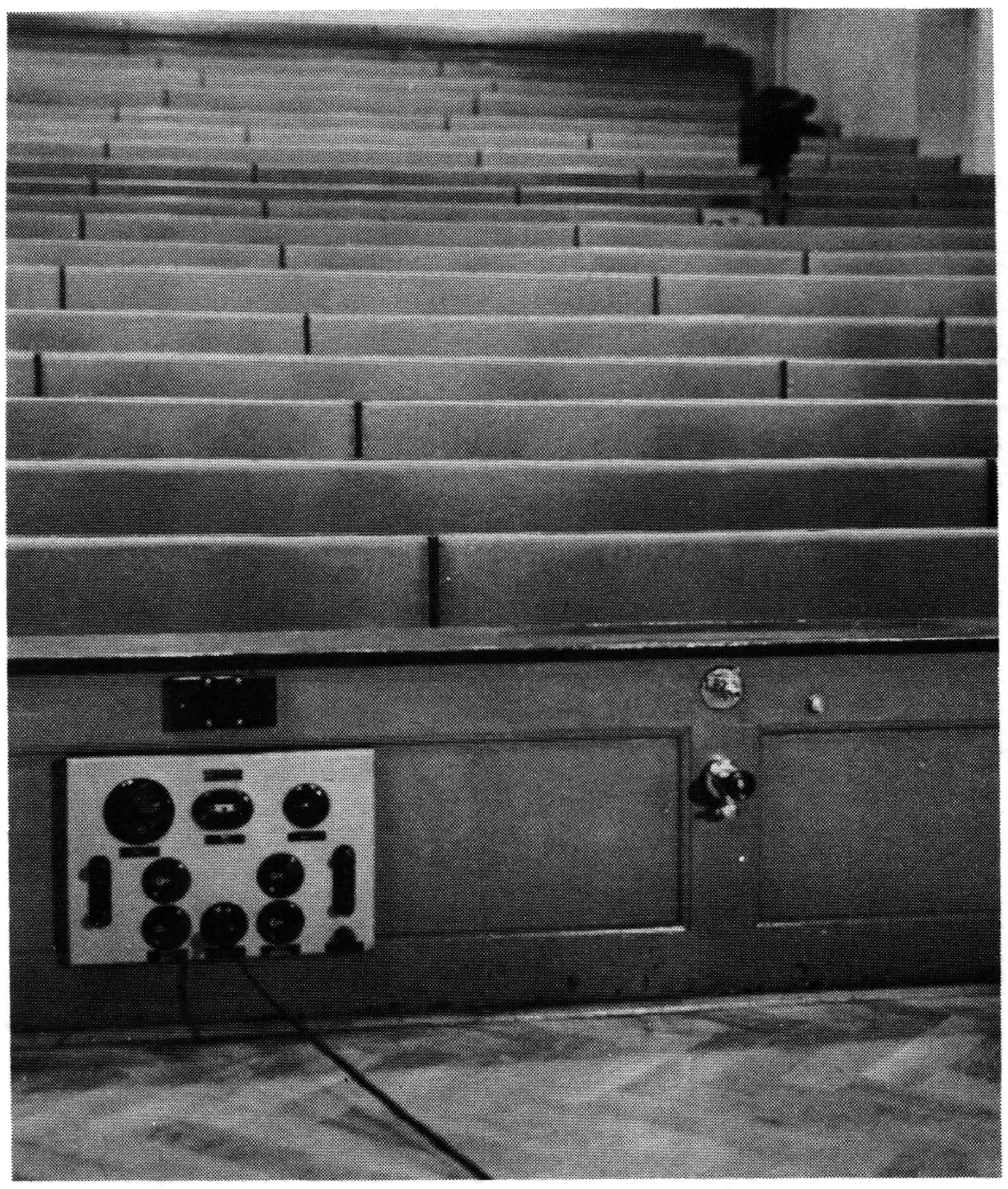


Figure 29. Narrow lecture table (or service island) in one of the physics lecture rooms at Louisiana State University. Movable tables are placed in front of the table to support apparatus for demonstrations.

Figure 30. Services are mounted in a service rail at the University of Göttingen, leaving entire area between rail and front wall clear for movable tables and optical projectors.



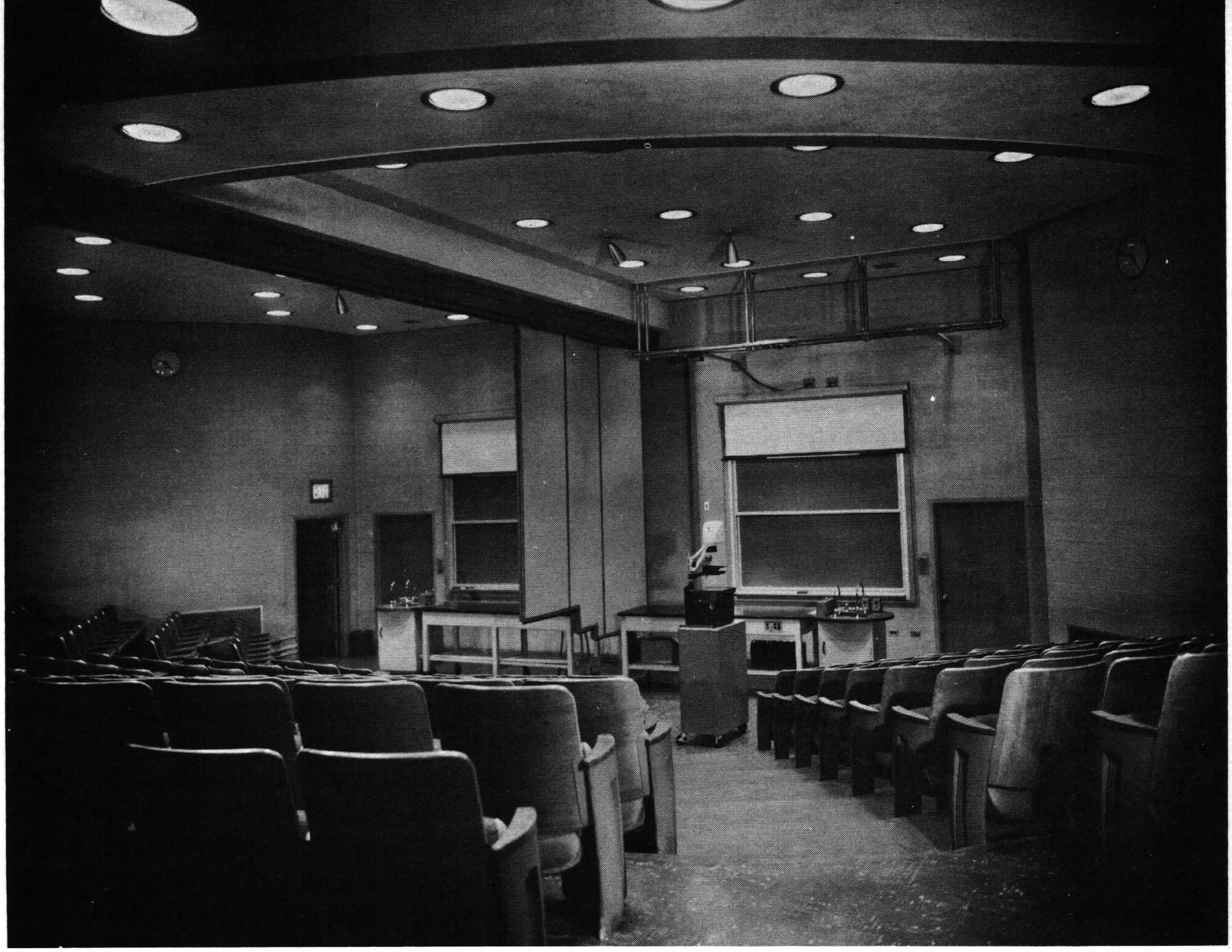
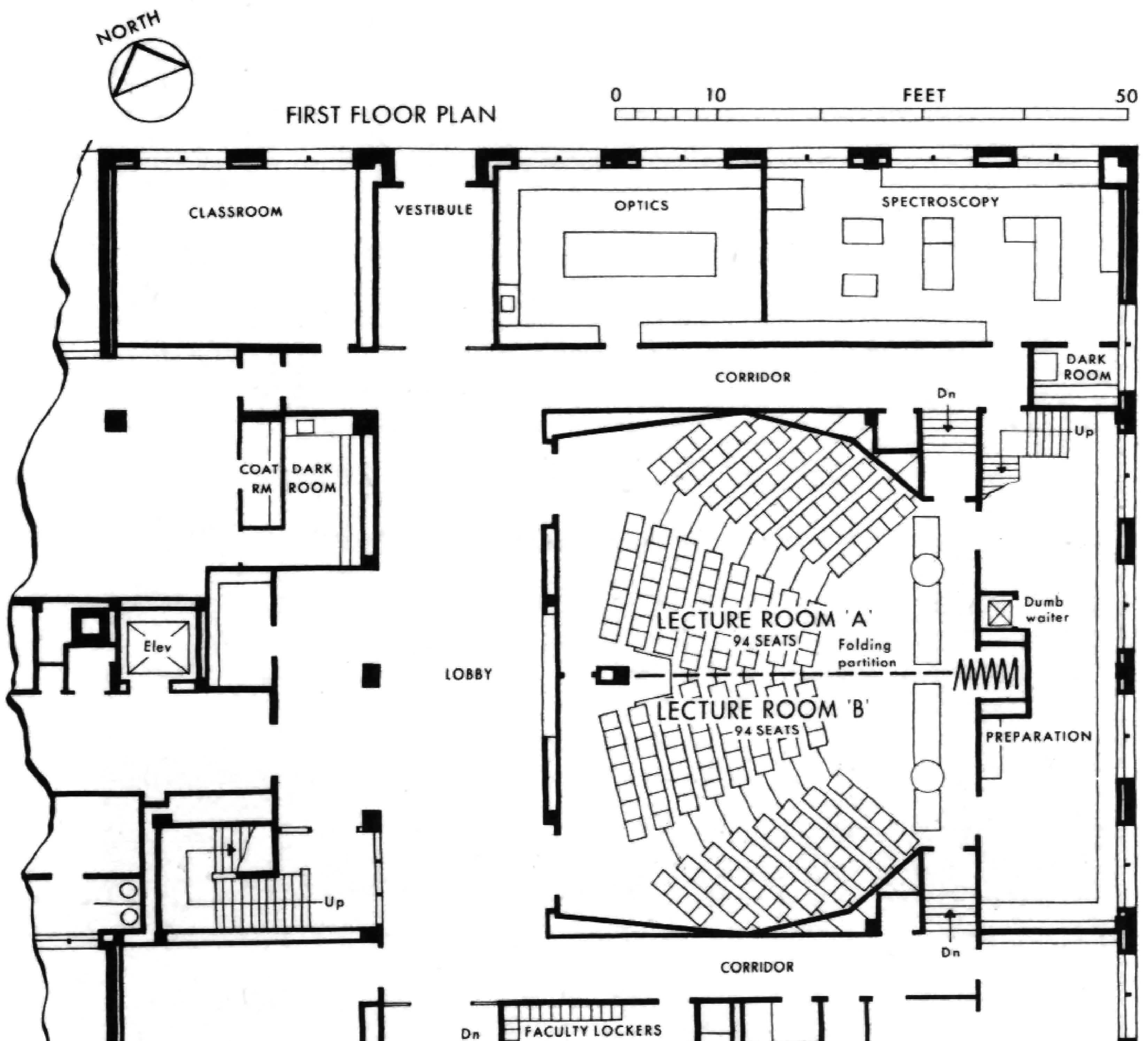


Figure 31. Lecture hall in the new Science Building, Drexel Institute of Technology. Baader, Young and Schultze, Architects, Philadelphia, Pa. Note the folding partition which divides the hall into two lecture rooms.


NORTH
FIRST FLOOR PLAN
0
10
FEET
50
CLASSROOM
VESTIBULE
OPTICS
SPECTROSCOPY
CORRIDOR
DARK ROOM
Dn
Up
COAT RM
DARK ROOM
Elev
LOBBY
LECTURE ROOM 'A'
94 SEATS
Folding partition
Dumb waiter
LECTURE ROOM 'B'
94 SEATS
PREPARATION
Up
Dn
CORRIDOR
FACULTY LOCKERS
Dn
OFFICE
VESTIBULE
M
OFFICE
OFFICE
OFFICE

may be desired, and a hood should be added. The hood must have a good draft to take away fumes which will otherwise corrode instruments and apparatus which the physics department may have mounted in the room. Furthermore, each department should have its own storeroom and demonstration preparation area.

The 200-seat lecture room in the duPont Science Building at Swarthmore is designed for both physics and chemistry (Figure 3). Each has its own storeroom, with separate doors opening directly into the lecture room. A large hood is installed behind the movable chalkboard in the center of the front wall. The hood opens into the adjacent preparation area as well as into the lecture room, and thus permits demonstrations to be set up in the hood while the lecture room is in use.

A somewhat less effective removal of fumes can be provided by a portable down-draft hood which can be placed over an exhaust vent at one end of the lecture table and then removed when not needed. In any event, chemistry instructors should avoid demonstrations which produce an excessive amount of corrosive fumes.

The 188-seat lecture hall in the new Science Building at Drexel Institute of Technology can be divided down the middle by means of a movable partition (Figure 31). The partition is moved by electric motor and is folded back into a recess at the front of the room when the room is needed undivided for a large class. The view in Figure 31b shows the partition part way out. The right side of the room is normally used by physics (note the framework near the ceiling for supporting apparatus) and the left side for chemistry, and separate doors are provided to the respective storerooms. A pedestal with a circular top is installed in each area to provide electrical and mechanical services for demonstrations. Movable tables which match the pedestal are used for demonstration setups. We are informed that classes can be held in both sides at the same time if neither lecturer raises his voice above normal. Sound movies cannot be given on one side while a class is in session on the other.

APPARATUS STOREROOM AND PREPARATION AREA

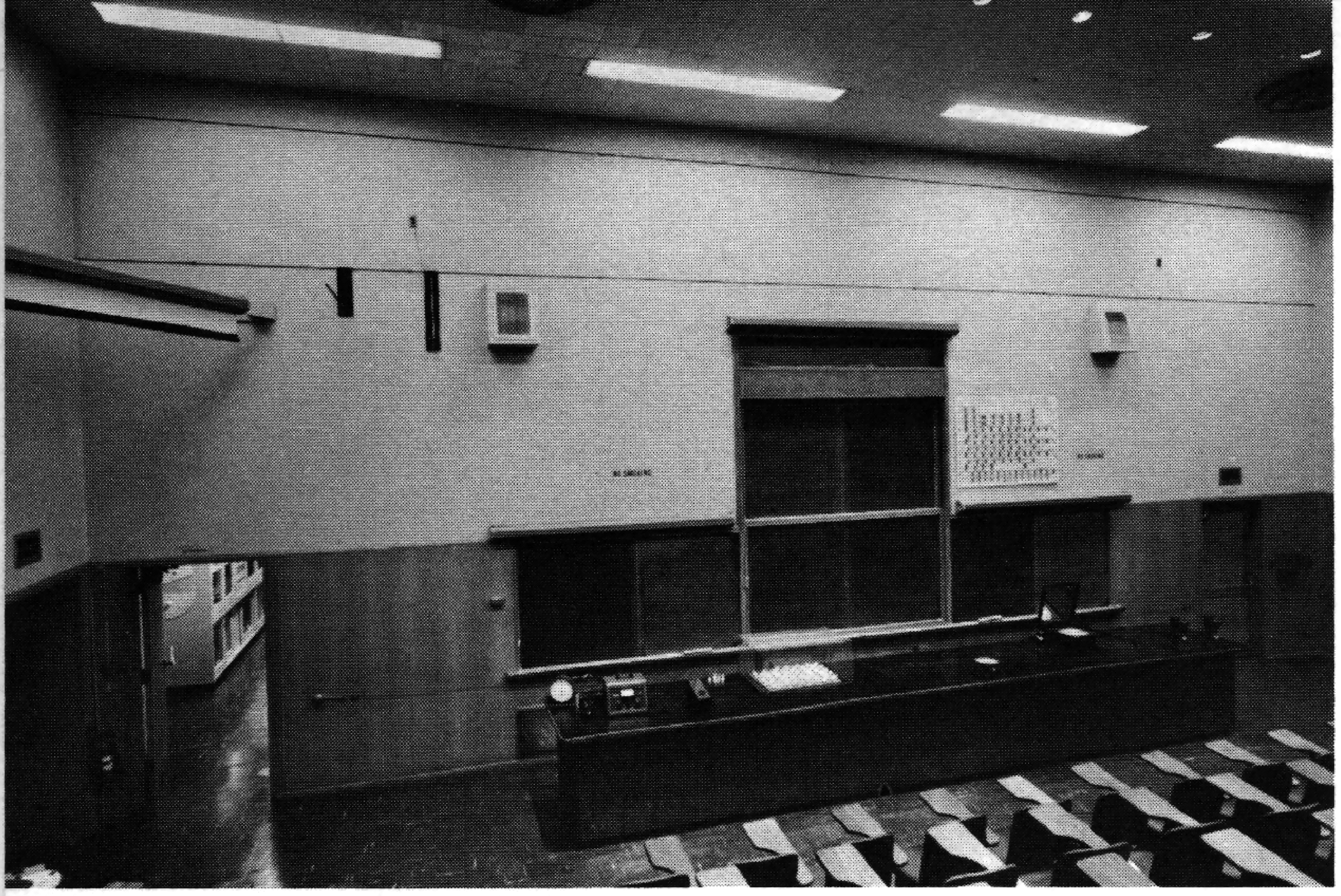
A separate room is required for storing the large amount of apparatus required for physics lecture demonstrations. Good storage practice requires that the apparatus be kept clean and in good working order and that it be readily accessible. This requires not only adequate cases, shelves, and drawers but also an area where apparatus can be set up and its operation checked, and where minor repairs can be made when necessary.

Location of Storeroom

To simplify the task of setting up apparatus for lecture demonstrations, the storeroom should be adjacent to the front of the lecture room. There should be a door between the two rooms so that apparatus can be moved from one room to the other without having to go through a corridor. Furthermore, the door should be located so that the path can be as direct as possible and so that it is not crossed by student traffic. These requirements are not only for the convenience of the staff; they also serve to protect delicate apparatus from harm and to minimize the amount of last minute readjustments that may be required.

The floor plans in this chapter and in Chapter 4 show a number of different ways of relating the storeroom to the lecture room. The arrangement at Pomona College (Figure 2), with the storeroom at one side of the lecture room, provides a direct path which is particularly convenient for rolling tables between the two rooms. Furthermore, there is no interference from student traffic since students enter and leave by the door at the rear of the room. (The door at the front is an emergency exit only).

The apparatus storerooms at Massachusetts Institute of Technology and at the University of Florida are directly behind the front walls of the lecture room and extend the full width of the room in each case. The two rooms are connected at M.I.T. by double doors on each side of the chalkboard (Figure 6). At Florida, a pair of doors in the center of the front wall can be rolled back to provide an opening 20 feet wide between the two rooms (Figure 5). With this arrangement, a large piece of apparatus can be set up in the storeroom and demonstrated with the doors rolled back without having to move it into the lecture room. Note that when a platform is installed in a lecture room, as at M.I.T. and at Florida, the floor of the storeroom should be at the same level as the platform so that carts and rolling tables can easily be moved between the two rooms. And



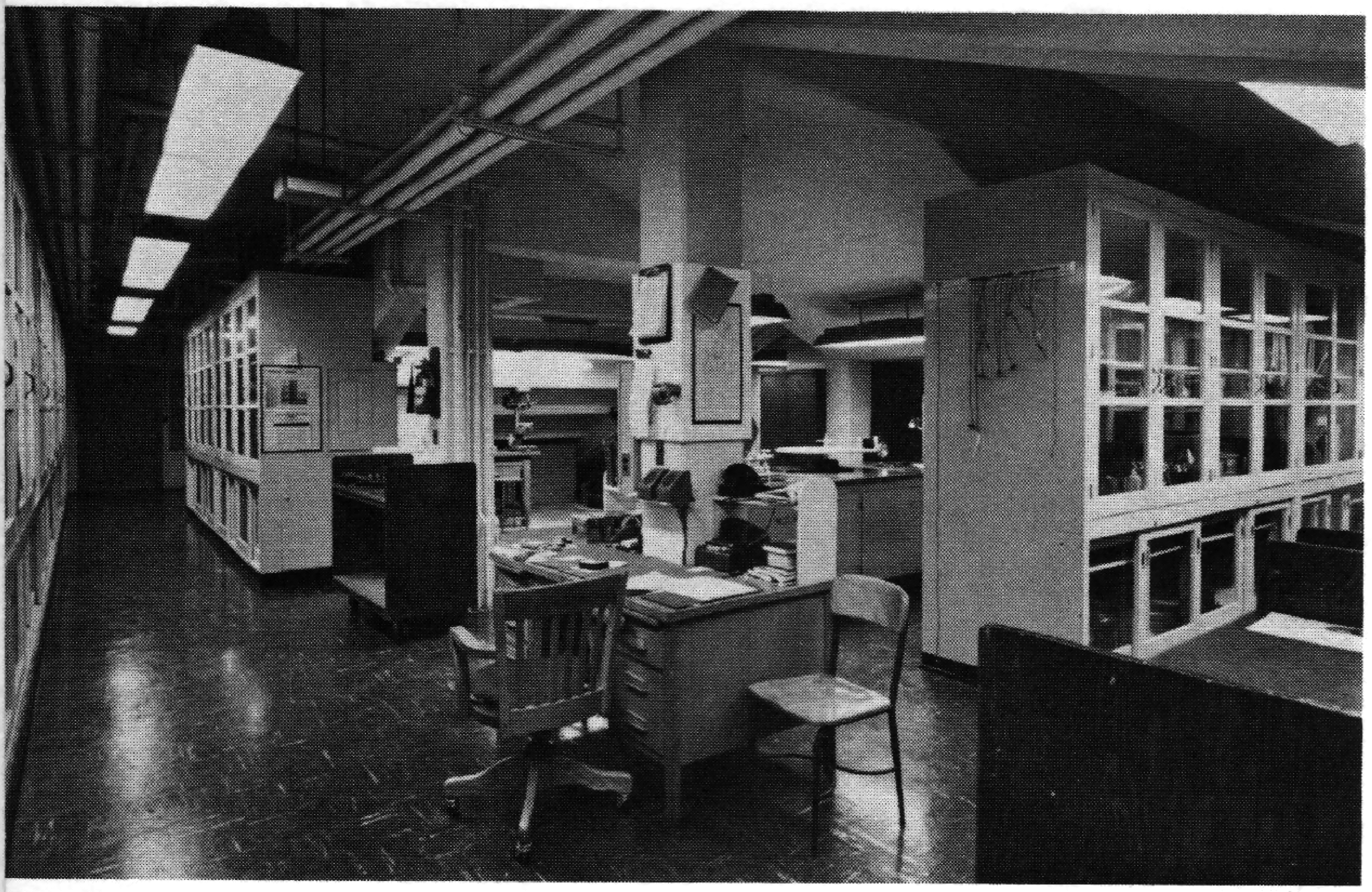


Figure 32a. Lecture room in the LeConte Addition to the Physics Building at the University of California, Berkeley. Note door to apparatus storeroom at left. Figure 32b. Apparatus storeroom which serves four lecture rooms adjacent to it.

in no case should there be a raised sill in the doorway between the two rooms.

Two lecture rooms can be served by the same storeroom when the two rooms are located on opposite sides of the storeroom, as in the Physics Lecture Hall Building at Stanford University (Figure 1). Notice that double doors are installed between the two rooms, and that in each case these doors are so located that student traffic will not interfere with the movement of apparatus between the two rooms.

Three lecture rooms can be served by a common apparatus storeroom, as is done at Brigham Young University (Figure 8). The departments of physics, chemistry, and geology are each provided a similar array of lecture rooms in the Science Building at Brigham Young University. (See Figure 17 in Chapter 4). Alternative, convenient arrangements of three physics lecture rooms and a common storeroom are used at the University of Minnesota[1] and at the University of Pennsylvania.[10]

Four lecture rooms are grouped around a common storeroom in the LeConte Addition to the Physics Building at the University of California in Berkeley, one lecture room at each end of the storeroom and two smaller rooms along one side, as shown in Figure 1, Chapter 4. Figure 32a is a view in one of the end lecture rooms, with the door to the storeroom left open. Some of the storage cases are visible through the open door. Figure 32b is a view inside the storeroom and was taken from a point next to the cases shown in 32a.

Storage Facilities

An extensive array of cases, shelves, drawers, bins and racks is needed to store the apparatus and incidental materials needed for physics lecture demonstrations. Both metal and wood furniture are used. Metal is widely used for racks, open shelves and small chests of drawers as in Burr Hall at Harvard (Figure 33a). Note also in this figure the large chest of drawers on the far wall for storing slides. Wood is widely used for closed cases, as at Berkeley (Figure 32b). Glazed doors should be provided on closed cases; this is particularly necessary for locating apparatus when more than one person puts things away. Even though a system of marking apparatus clearly indicates where each item should be stored—and each department should have such a system—things do not always get put back where they belong.

Apparatus must be stored in an enclosed space to keep it properly protected from dust. Dust on apparatus is not only unsightly but it may also damage the apparatus and impair its operation. However, it is much simpler to store apparatus on open shelves than in cases with doors. It is for this reason that the "walk-in" cases shown in Figure 33b were installed in the storeroom in Burr Hall. Each one of the doors shown opens into a small cubicle that has open shelves on each side. Apparatus can easily be removed from and replaced on the shelves. Furthermore, each cubicle is quite dust-tight when its door is closed.

Storage cabinets and shelves are normally about 2 feet deep. A few cabinets should be somewhat deeper to accommodate large pieces of apparatus but not many such cabinets should be installed, for small pieces get lost. Shelves in cabinets should be adjustable in height. Drawers of different depths and widths should be provided.

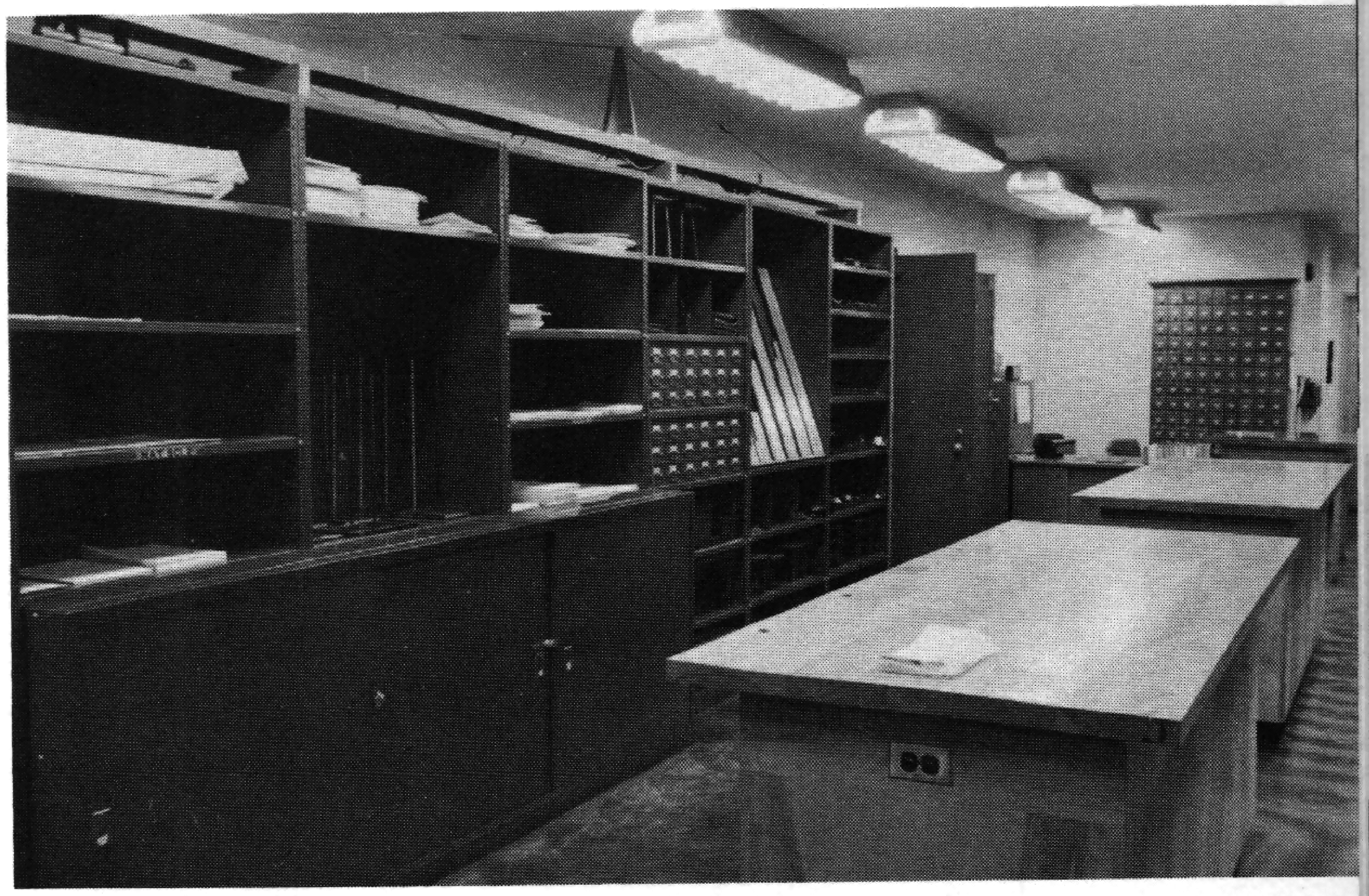
Preparation Area

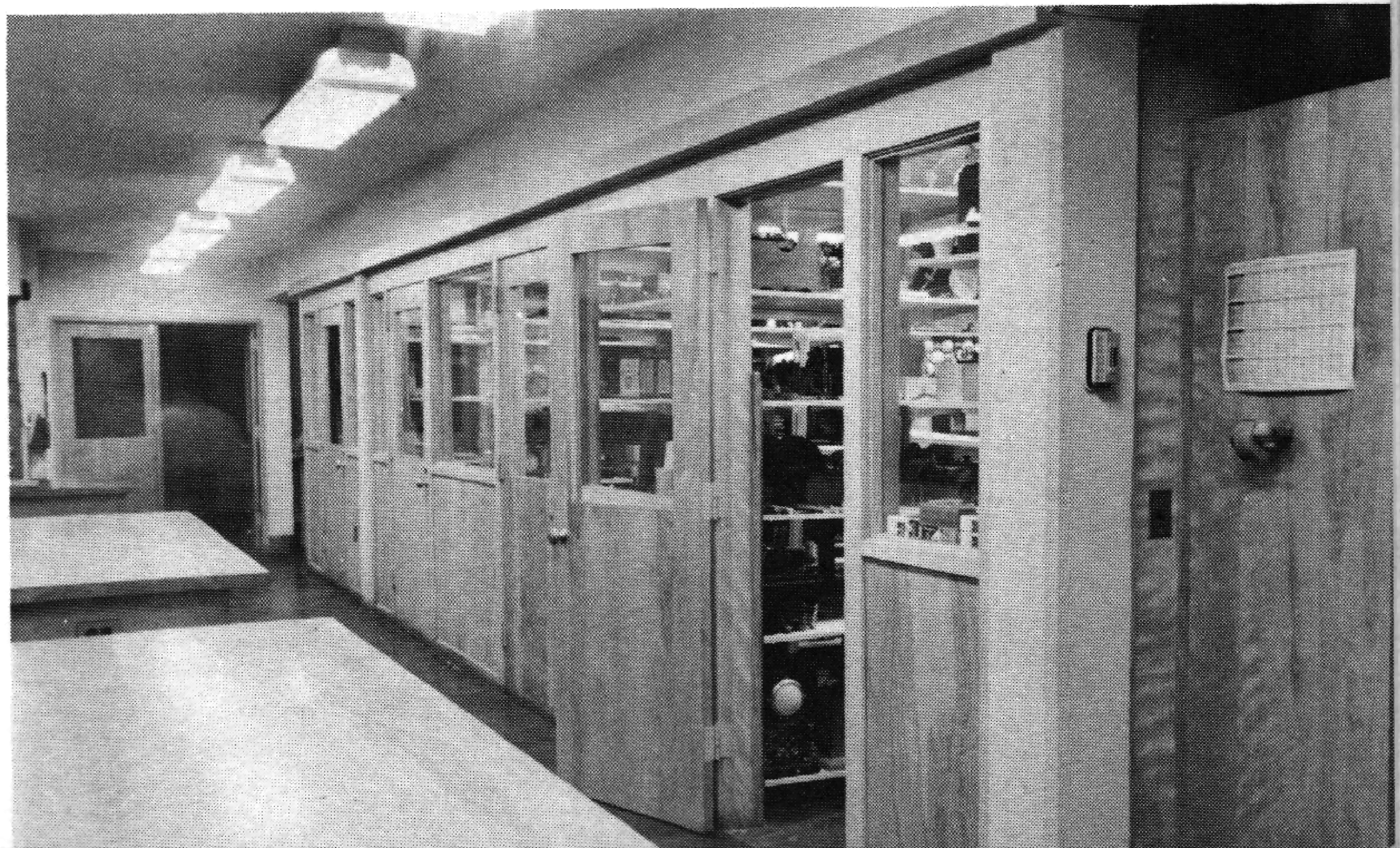
An area must be set aside in a storeroom where apparatus can be set up and tested in preparation for a lecture. This is usually done on fixed tables, and carts are subsequently used to roll the apparatus into the lecture room. The built-in tables in the Burr Hall storeroom shown in Figures 33a and 33b are designed for this purpose. So that the apparatus can be tried out under the same conditions as it will be used, the tables and associated utilities (except for water) are duplicates of those in the lecture rooms. The preparation table in the storeroom at Stanford University (Figure 1e) is also a duplicate of the tables in the two lecture rooms.

Lightweight metal carts for transporting apparatus are available commercially. Wooden carts can easily be constructed in the college shop. A unique yet simple idea has been incorporated in the wooden carts constructed at Berkeley. One of these carts appears at left center in Figure 32b. The cart has two shelves, with the upper shelf about the same height as the lecture tables and the table in the preparation area (36 inches). However, the shelf on the cart is purposely set so that it is not quite horizontal; one side is about ⅛ inch lower than the other. Heavy apparatus can therefore readily be slid from cart to lecture table and vice versa, always working from high to low, without catching on the edge of either. To carry the idea one step further, the lowest shelf in all of the upper cases is carefully installed to be at the same 36-inch level as the center of the carts. All heavy apparatus is therefore stored in the cases at this level and can readily be transferred to and from the lecture room by cart.

At a number of institutions the lecture table is made small purposely, and movable tables are used for the lecture demonstration setups. For example, the lecture table at Colorado State University is only 36 by 40 inches in cross-section—no larger than needed for mounting the necessary electrical

Figure 33a. Storage area on one side of the storeroom in Burr Hall, Harvard University. Figure 33b. Series of closed cubicles (walk-in cases) in the storeroom.





and mechanical services (Figure 25). The movable tables match the fixed table in height and are equipped with electrical outlets which can be connected to the fixed table by flexible cable. Several movable tables are usually available; at Colorado there are three—9, 7, and 5 feet in length. Where movable tables are used, a pier or fixed table similar to the lecture room table is usually installed in the preparation area so that lecture room conditions can be duplicated as nearly as possible when apparatus is being set up for a demonstration lecture.

A work bench with a vice and a set of hand tools should be the minimum amount of shop equipment provided in the preparation area. A small drill press would be the next most useful addition. If one or more technicians are assigned to the storeroom, a separate shop area equipped with a few power tools should be provided. Such a shop is located in a mezzanine area above the storeroom in the Lecture Hall Building at Stanford University (Figure 1). Besides the necessary hand tools, a drill press, lathe, grinder, wood and metal band saw, and a vertical milling machine are installed in this shop. The staff reaches the shop by way of the spiral stairs shown in Figure 1. Bulky and heavy apparatus is moved between the two floors by means of a hoist and an opening in the floor. A small woodshop is provided in a separate room on the same floor as the storeroom. Besides the necessary hand tools, it contains an 8-inch table saw, 4-inch jointer and a 4-inch belt sander. Major shop jobs are referred to the departmental shop.

At least one pair of free lines should run between the lecture room and the preparation area for special currents and for signalling. A buzzer system or a signal light, or possibly an intercom, should be installed between lecture room and storeroom.

Size of Storeroom

The amount of space that should be allowed for an apparatus storeroom in a new building depends on the amount of demonstration equipment on hand (after useless or obsolete apparatus has been culled out), and the amount of equipment that is likely to be added in the next couple of decades. It is the latter factor that is difficult to estimate. It depends for one thing on the size of the lecture room; if the lecture room is appreciably larger than the department has used in the past, the apparatus that is added to the collection must be larger, and more space will be required for storing it. The amount of apparatus to be added will also depend on the extent to which the staff desires to use apparatus for demonstrations, and particularly on the staff's enthusiasm for developing new apparatus. The need for more apparatus may be partially offset by plans for using other aids to instruction such as increased use of shadow projection, movies, and TV. However, most physics instructors believe that there can be no substitute for a live demonstration, that a recorded or second hand presentation cannot possibly be as effective. More storage space, rather than less, will most likely be required in the future for good demonstration apparatus.

The floor plans in this chapter and in Chapter 4 will give an idea of the amount of space devoted to apparatus storerooms in recently constructed physics buildings. Some of these rooms are admittedly too small. It has been suggested by the staff at one of the institutions that after one has considered carefully how large the storeroom should be, he should increase his figure by at least 50% for the final plans. This also holds for the amount of cabinet space required.

TELEVISION AND PHYSICS LECTURES

Television is being extensively tested as a means of bringing education to large numbers of persons. Physics courses have been taught exclusively by television, and also by television lectures that have been recorded on film.[11] The Educational Facilities Laboratories, Inc. has reported a study of educational television entitled *Design for ETV-Plan-*

ning for Schools with Television.[12] The following paragraph is quoted from this report: "Why has television proved so effective when other projection and filming techniques have had only lukewarm reception in the past? Of audio-visual tools available, television appears to offer the broadest potential. The teaching image is easily transmissible by air and cable. It is reproducible from magnetic tape. It is viewable at relatively high ambient light levels without the need for darkening a room. It permits viewing of current events concurrently with the occasion. Taped programs, entire courses or laboratory demonstrations may be banked in libraries for use as required. Such tapes and/or programs for the slow learner or the advanced student may serve to enrich the gifted and help the slow. The viewing and audio instrument itself is relatively inexpensive, easily used, widely available and easily maintained. The arts of the industry are rapidly improving receiving, transmission, recording, and production equipment."

Television as an Aid to Demonstration

As suggested by the paragraph just quoted, television can be used in a variety of ways for the teaching of physics. However, most physics instructors believe that, as of 1960, television can make its most significant contribution to the teaching of physics in our colleges and universities as an aid to lecture demonstrations. A number of departments of physics accordingly have purchased TV equipment—normally just a single TV camera, power supply and set of controls, and one or two monitors. Conventional 21-inch TV sets can be used as monitors, and sets with larger screens can be used for greater viewing distance. The equipment used for lecture demonstrations by the physics department at Oberlin College is shown in Figure 34. The camera is mounted on a tripod and the monitor is on a cart that can be moved to any convenient position for viewing. Floodlights are available for increased localized illumination.

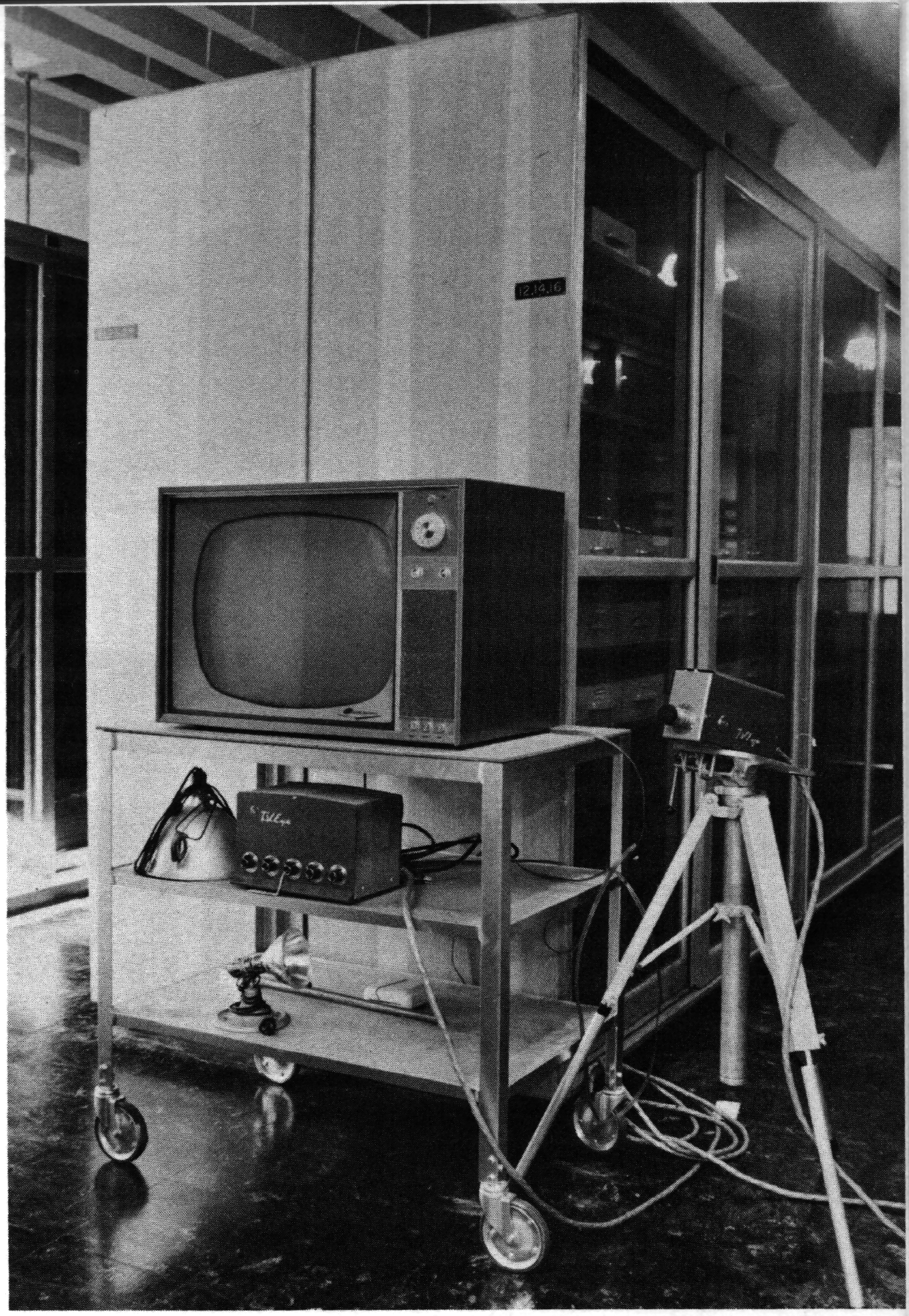


Figure 34. TV equipment in the physics demonstration apparatus storeroom at Oberlin College.

A variety of demonstrations that can be seen by no more than one or two persons at a time can readily be shown to a large group by TV. Small pieces of apparatus or small component parts of a piece of equipment can be magnified to the size of the TV screen, and seen at a greater distance. The TV camera can be used with a microscope to show such effects as Brownian movement and crystal growth—effects which otherwise could be seen by but one person at a time. Experiments can be televised in other areas

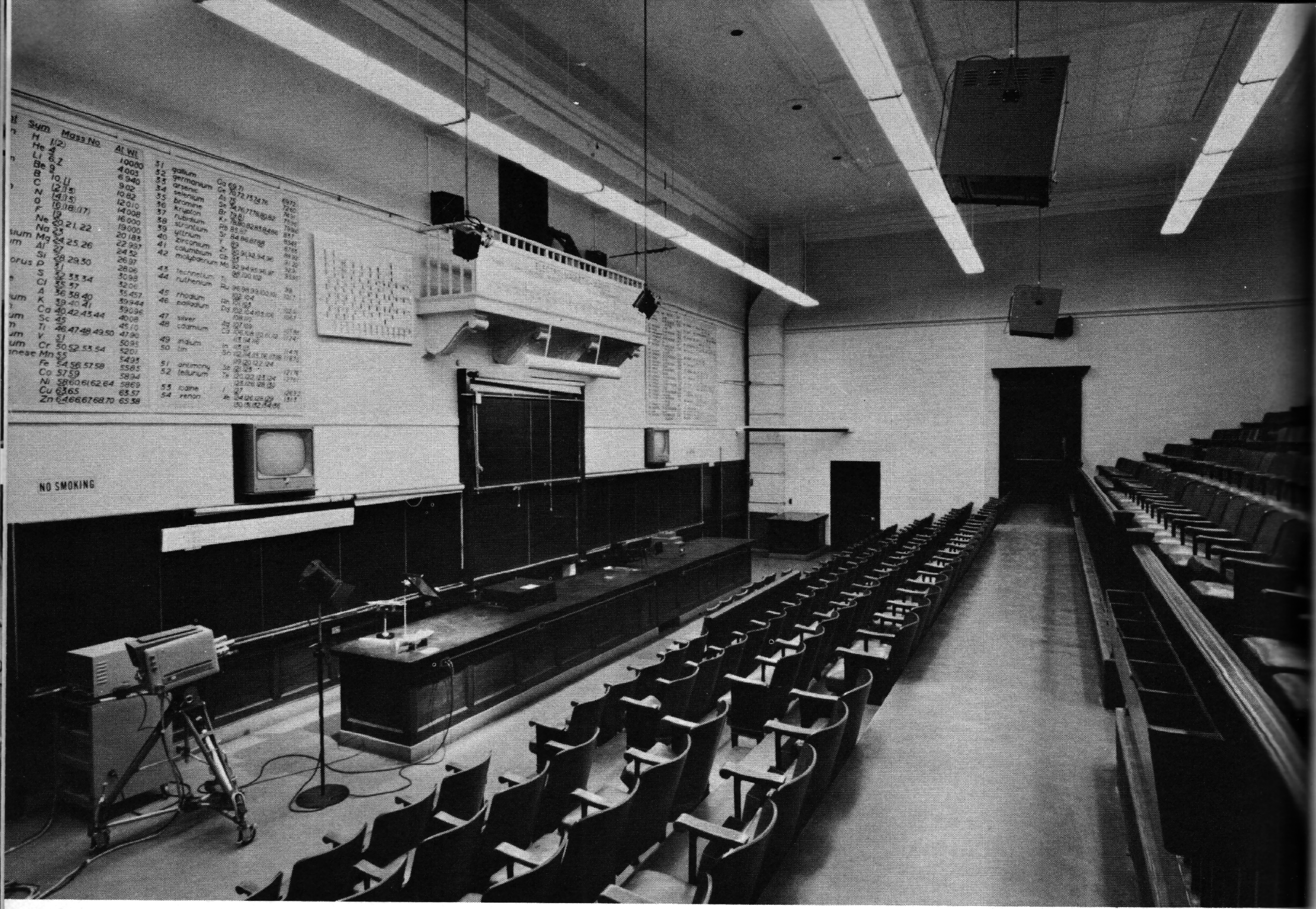
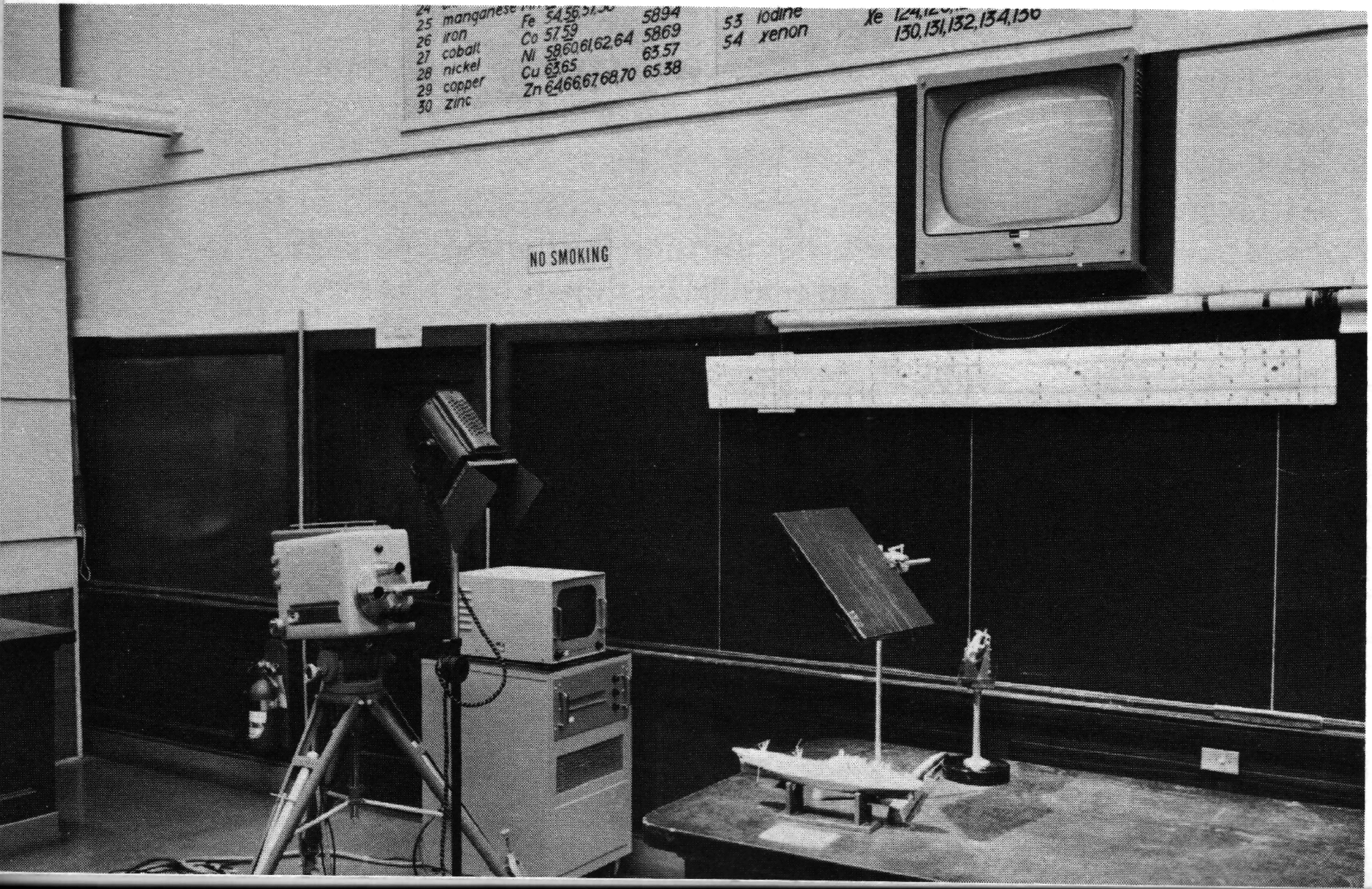


Figure 35. View of large lecture room in the Physics Building at the University of California (Berkeley) showing TV equipment. Note monitors above chalkboards on front wall and suspended from ceiling. Photograph below shows TV camera and small monitor at lecture table.


25 manganese
26 iron
27 cobalt
28 nickel
29 copper
30 zinc
53 iodine
54 xenon
NO SMOKING

of the building and shown by closed circuit TV in the lecture room. By this means experiments under way in research laboratories can be explained to a large class. Apparatus can be viewed that could not or should not be moved. Furthermore, with TV equipment, programs that originate elsewhere on the campus or which are broadcast on regular channels, can be presented in the lecture room.

Several monitors, of course, are needed for a large lecture room. Figure 35 shows the installation of television equipment in the large 400-seat physics lecture room on the Berkeley campus of the University of California. Notice that two monitors are located on the front wall above the chalkboard and two others hang from the ceiling part way back for the benefit of persons in the rear of the room. A small monitor is mounted on the control cabinet adjacent to the camera to assist the instructor in making adjustments

An illumination of from 50 to 100 footcandles is adequate for cameras which use the image orthicon tube. Several times this amount of light is needed for the less expensive vidicon tube.

The maximum satisfactory viewing distance for a television monitor depends on its size and the nature of the material to be viewed. As mentioned earlier, for optical projection on screens, standard practice has set the maximum distance as six times the width of the screen. Current practice for television viewing has accepted twelve times the width of the screen as the maximum distance. This means that a 21-inch (diagonal) TV set 18 inches wide can be viewed satisfactorily up to a distance of about 18 feet.

To determine the size that symbols must be to be legible, one can make a calculation similar to that made in an earlier section when discussing the visibility of chalkboard writing. If symbols need to be 2 inches high for viewing at 50 feet, they must be about ¾ inches high for viewing at 18 feet. Clearly this severely limits the amount of material that can be legibly displayed at a time.

The number of persons who can satisfactorily view a given monitor is limited by angle as well as by distance. Students seated so that their line of sight makes an angle greater than 45° from the normal to the face of the monitor get too distorted a view of the screen.

Good sight lines are required for a TV monitor just as for any demonstration which one wants students to see. Monitors must therefore be set high enough so that one row of students does not obstruct the view for those behind them. However, monitors should not be mounted too high. For prolonged comfortable viewing, one's line of sight should not be more than about 30° from the horizontal.

Teaching by TV

A number of experiments have been conducted in which sections in beginning physics have been taught exclusively by TV. This requires more elaborate equipment than described in the preceding section. The EFL publication mentioned previously analyzes the problem of teaching by TV, describes various procedures that can be used, the equipment that is required, and lists costs. As a minimum, one must equip a studio in which the lecture demonstrations can originate, and run cables to the classrooms or other viewing areas that have been selected. With professional equipment and a professional staff, one can use a number of techniques to obtain special effects which can even be more effective for certain presentations than a conventional live demonstration lecture.

However, there appear to be psychological barriers to overcome. Students seem to prefer a live performance to a TV presentation when they have been given a choice between the two. Furthermore, most instructors still prefer to face a live audience than a camera and a microphone.

Another barrier is economic. The professional equipment and staff required for an effective program is expensive to assemble and to maintain; and very few institutions, if any, have an enrollment in physics that is high enough to make teaching a physics course exclusively by TV economically feasible. To be sure, duplicate lectures must be given in many institutions, whereas the number of students that can be taken care of by a single TV lecture is limited only by the number of receiving sets that can be installed and the number of persons each set can accommodate effectively. Furthermore, when the cost of video tape equipment reaches a level that educational institutions can afford, once a lecture has been recorded, it can be repeated any number of times. It should, of course, be noted that the preparation of a TV lecture demonstration requires much more time than a conventional lecture, and this partially offsets the advantage of the single presentation. However, with increasing enrollment, a time will come when it will be economically feasible for many institutions to make more extensive use of TV in the teaching of physics.

Television and the Design of Physics Buildings

Conventional physics lecture rooms can readily be adapted to TV, both as studios for the production of televised lectures and as satisfactory viewing areas if monitors are properly placed. Furthermore, conventional classrooms can serve satisfactorily as additional viewing areas. To extend television viewing into the classrooms, it is necessary merely to install the required coaxial cable between the classrooms and the lecture room. If one desires to use a portable camera for televising experiments in research laboratories, additional cable must be installed.

In designing a new physics building it is only reasonable to plan for an expanded use of TV. All cables that may be required in the immediate future should be installed when the building is built. Furthermore, since it is impossible to anticipate all future requirements, paths should be left open to other areas of the building so that cables can readily be extended as required.

When the use of television has expanded to the point that a special studio is required, a classroom fitted with the facilities for lecture demonstrations can be converted to a studio, and this should not require major structural changes. The EFL Report describes the physics facilities required for educational TV and how they will affect school architecture. The following conclusion is of interest to persons planning new buildings.

"One of the major purposes of this design study as outlined by EFL was to determine to what extent the use of television affected the facilities, size, shape and structure of the learning area. Our conclusion is that the tail does not wag the dog as might have been expected. Structural allowances must be made for proper installation of conduit or raceway to carry the cables for closed circuit transmission. Studios or classroom facilities used for origination of a program require special wiring, lighting and ventilation. Beyond these considerations, no special architectural allowances are imposed for television reception in the school."

6. Classrooms and Seminar Rooms

INTRODUCTION

The classroom is a traditional teaching facility for undergraduate and graduate physics courses in our colleges and universities, and is likely to remain so for a long time to come. In contrast to large lecture rooms it provides an opportunity for the teacher to meet with his students in relatively small groups and serves in a variety of other ways. In advanced courses with small enrollments the classroom is often used as a small lecture room in which the instructor delivers a lecture with extensive use of chalkboards and occasional use of common visual-aid devices such as slide projectors; in elementary courses it is commonly used for small groups, often called recitation sections, selected from the large general physics enrollment, to supplement lecture and laboratory. Students in these recitation sections are usually encouraged to ask the instructor questions; the instructor may ask the students questions or assign a number of students to solve problems at chalkboards to stimulate class discussion. This kind of two-way communication between teacher and students is best obtained with small numbers of students in a small room with adequate chalkboard space and good acoustics. An individualized approach to instruction is thus provided in a way that is not possible in the more formal lectures given in large lecture rooms.

GENERAL CHARACTERISTICS

Location

Since classrooms are periodically attended by relatively large numbers of students, they should be strategically located to provide easy access to and from them. This minimizes interference with other departmental activities from the heavy traffic when classes assemble and dismiss. Conventional "hour" class periods last 50 minutes, allowing 10 minutes for students to go from one class to the next, although periods of 90 minutes have been tried at some institutions. Adequate corridors are essential, and if classrooms are located on both sides of the corridor, their doors should be staggered along the corridor to reduce traffic congestion when classes are dismissed. Additional relief from congestion can be provided by having ample building exits reasonably near to the classroom doors, and when classrooms must be located on upper floors, wide stairways will speed the flow of student traffic. At one institution, all classrooms are concentrated on one upper floor, the corridor of which leads to relatively spacious stairwells at each end. One of these stairways is used much more than the other because it provides a more direct path to other parts of the campus and in this case, double doors have been installed at each floor to afford some relief from traffic disturbances to people who are at work on those floors. Many alternatives can be planned for the location of classrooms but in all cases consideration should be given to providing comfortable rooms of appropriate capacity and facilities, with adequate provision for the periodically heavy flow of student traffic.

Shape and Size

Judicious selection of seating capacities for classrooms is an important item in the design of a physics building. It is fairly common to find physics classrooms designed for 30 students and from the sole consideration of effective instructor-student intercommunication, this is a reasonable maximum size. However, with the recent rise in physics enrollments, experience at a number of institutions shows that a range of sizes meets their needs better than only one size. Thus, for example, enrollments in intermediate and advanced courses now frequently exceed 30 in many schools and one or more rooms with a seating capacity of 40 or 50 can meet this need; yet these slightly oversized rooms are not too large to accommodate recitation sections of 20 or 30 students. Rooms appreciably larger than those that hold 50 students begin to approach small lecture rooms for which facilities for lecture demonstrations may be desirable. These large classrooms or small lecture rooms have also been found useful where physics classrooms are shared by other departments, in which classes are appropriately made slightly larger than 30, or for lectures with demonstrations to special groups such as pre-medical students. In any event, instruction is more effective in a room that at least approaches an approximate match to the class size; and while most classrooms should seat about 30, there appears to be a real need at most institutions for a limited number of intermediate-sized classrooms with or without demonstration facilities.

At one institution we visited, 40 chairs were crowded into a room designed for 30. At another, regret was expressed that all six classrooms were made the same size—to seat just 30 students, with no room of intermediate size between these and the lecture room which seats 250.

Although requirements of different institutions are subject to widely different overall conditions it may be helpful to illustrate the solution to the classroom problem at a moderate-sized school by presenting specific numbers for one example. At this school the approximate total enrollment in undergraduate physics is 600, including 60 majoring in physics; about 75 students are enrolled in graduate physics courses. Four available classrooms seat 18, 24, 24, and 42, and there are two fully equipped lecture rooms—one with a capacity of 54 and the other 190. On rare occasions the lecture rooms are also used for recitation sections.

Classrooms are conventionally rectangular in shape, probably because this shape can be most readily fitted into rectangular buildings. In nearly all cases, classroom shapes and sizes are essentially fixed at the time of construction.

Perhaps the most notable deliberate innovation in classroom shape is illustrated by the design of three adjacent classrooms in Burr Hall at Harvard University; the front part of each room is narrowed as shown in Figure 1. This shape improves the visibility of writing and inscriptions on the chalkboards which are mounted on the narrowed walls, and it also seems to enhance the utility of these rooms for instructor-student communication in small discussion groups. The triangular space between walls need not be waste space, for it is available for display cabinets in the corridor or as duct space for services.

Easily movable flexible partitions are occasionally installed for the purpose of subdividing or otherwise changing the shape or size of a large room. It should be pointed out that currently available flexible partitions are not good sound barriers—classes cannot be conducted satisfactorily on both sides at the same time. Such partitions do enable one to create an area which conforms more nearly to the size of a small group, or to shut off part of a large room for some other reason. However, as mentioned in Chapter 3, several manufacturers and acoustics laboratories are working on the problem of creating a more nearly soundproof partition that is not only movable but which can be produced at a cost which will not price it out of the market. There are optimistic reports that this will be accomplished.

Acoustics

The two most important acoustical requirements for classrooms are (1) that the room shall be acoustically insulated from adjacent areas so that extraneous sounds do not interfere with the work in the room and (2) that its reverberation period shall be within the acceptable range for comfortable and efficient verbal communication between instructor and students. Since these rooms are usually small, there is no need for public address systems.

Many different factors contribute to the acoustics of a room, and it is especially important to evaluate the acoustical effect of every feature so that installations satisfactory from other considerations do not adversely affect acoustics. For example, a heavy coat of paint will improve the insulating qualities of a porous wall. Non-bearing walls which separate adjacent classrooms are frequently constructed of 4-inch cinder blocks which are available in a wide variety of densities and porosity, and hence, present a wide range of acoustical properties. At Purdue University, when one side of such a wall was plastered to decrease sound transmission it became necessary to install acoustic tile in

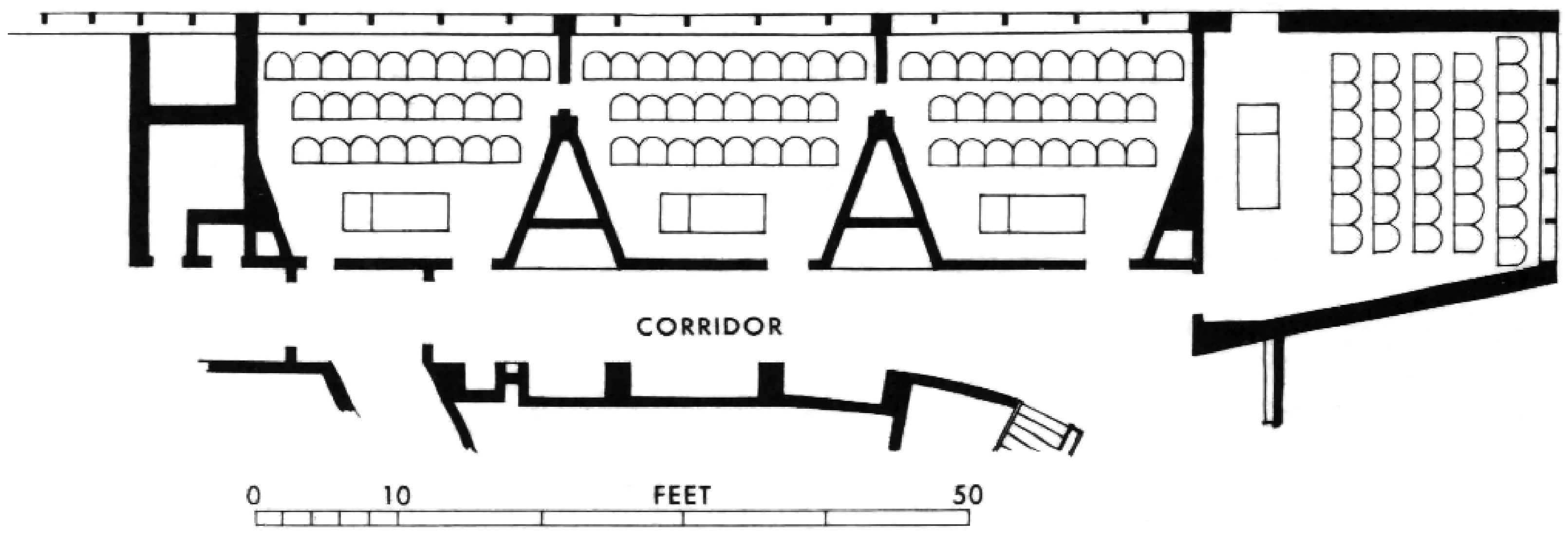
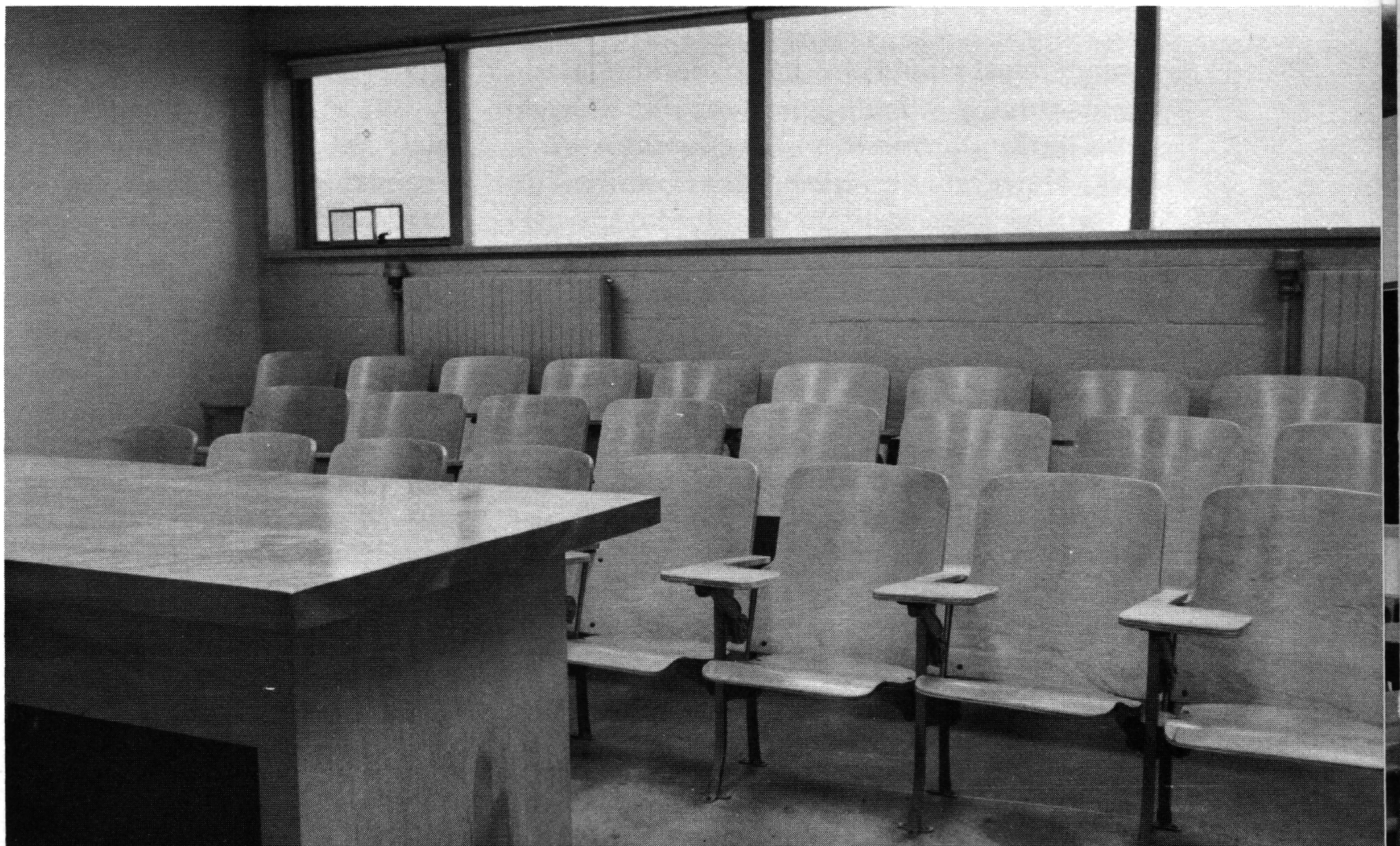


Figure 1. One of three classrooms in Burr Hall at Harvard University. Rooms are narrowed toward front—for effective discussion. Shepley, Bulfinch, Richardson & Abbott, Architects, Boston, Mass.



the room to decrease the adversely altered reverberation. In his book, Sabine states that "partitions of cinder or slag cement block should be plastered on one side at least to reduce direct transmission of sound through the porous body of such materials. The insulation of existing clay or gypsum tile partitions may be materially increased by adding a furred lath and plaster screen wall with strips of ½ inch felt inserted between the furring strips and the tile. Fiber board applied directly to an existing wall does not materially increase the degree of sound insulation."[1]

One of the most common defects of classrooms arises from their having reverberation times that are not conducive to good communication between instructor and student. Usually this deficiency is due to too large a reverberation time and this can be rectified by installing absorbing materials such as acoustic tile. The amount of acoustic tile required to reach the desired reverberation time can be estimated from the Sabine formula, given in Chapter 5 and the absorption coefficient of materials in the room. The optimum reverberation time should be in the neighborhood of 0.6 second for small classrooms and 0.8 second for large classrooms.

Lighting

Since most classrooms have windows, daylight is usually relied upon to provide at least some of the illumination necessary for class work. However, supplementary illumination is essential, especially on cloudy days, early or late on winter days and for night classes; the design of lighting facilities must be made on the assumption that no daylight is available. Even on a sunny day, artificial light may be necessary since some students may be uncomfortable with direct sunlight upon them, and if the blinds are closed, the general room illumination is too low. Poor illumination interferes with effective classwork. These and other considerations have led some physics teachers to express a strong preference for classrooms without windows, and a few rooms have been built this way such as the combination classroom-laboratory rooms at the Air Force Academy described in Chapter 7 (See Figure 14 in Chapter 7.) Considerations of lighting and chalkboard area favor windowless rooms. However, if the room has windows, they must be provided with blinds to control glare and to protect students from the disturbing effects of direct sunlight upon them.

It is important to have the level of illumination adequate at all parts of a classroom. The February, 1959 issue of *Illuminating Engineering* gives the current recommendations of the Illuminating Engineering Society for illumination levels for various school activities. These levels range from 30 foot-candles for reading printed materials to 70 foot-candles for reading pencil writing. If the expense seems too great to meet the recommended level for the poorest visibility condition, an average of about 50 foot-candles is a reasonable compromise in illumination level. Many classrooms in recently constructed buildings have approximately this level. It is desirable to have at the front of the room, chalkboard lights which raise the illumination on the board to about 100 foot candles—150 foot candles is recommended by I.E.S. Fixtures with reflectors mounted from the ceiling can be adjusted to concentrate light on the board without introducing glare to the students.

These illumination levels can be reached with incandescent or flourescent lamps but from most considerations, flourescent lamps appear to be superior. They are more economical to operate and they produce less heating, a factor that in warm weather adversely affects either student comfort or the cost of air conditioning.

Light switches should be located for the greatest convenience. If the room has more than one door, switches should be near each one and, depending on the size and shape of the room, anticipated normal room use might well indicate a need for other switches. Often it is desirable to have lights on more than one circuit. For example, if daylight from windows is expected to provide some illumination, lights for the part of the room near the windows can be on one circuit and those for parts more distant from the windows on another so that the latter could be lighted without the former.

Ventilation

In a typical classroom with 30 students a change of air is essential, especially when the room is used in several consecutive hours. Ventilation from windows is often objectionable to those students upon whom the draft blows and is always distracting to the instructor who may find it necessary several times in a class period to adjust the windows. Artificial ventilation can be a marked improvement over window ventilation in many circumstances but the recommended solution to this problem, especially in warm seasons, is thermostatically controlled air conditioning. However, whether complete air conditioning or merely forced ventilation is used, care should be taken to have the system sufficiently quiet not to interfere with class work. A ventilator can be seen above the classroom door in Figure 3.

CLASSROOM FACILITIES

Seating

The number of seats planned for a classroom of given floor area is often a compromise between the desire to provide the students with comfortable and adequate installations, and the need to economize by crowding the students. The amount of floor area per student seat in existing classrooms differs considerably because of (1) the variety of types of seats (2) the seating capacity of the room and (3) different allocations to aisle sizes for student traffic or to space for chalkboard recitation, but a survey of a few modern buildings shows that a classroom designed for 30 students has a total floor area of between about 400 and 600 square feet.

Although many types of seats are to be found in classrooms, there is always provision for each student to have some flat area upon which he can place his papers for writing. Most commonly used are single pedestal-mounted or four-legged chairs with individual tablet writing arms. A number of recently installed classroom seats include tablet arms that are considerably larger than those used in the past. In a few cases, provision is made for students sitting in individual swivel chairs on pedestal mounts to have a relatively large self-mounted table designed for the use of two students who are seated in pairs. A few types of recently adopted classroom seats are illustrated. The chairs in the small classrooms at Burr Hall mentioned earlier have folding seats (Figure 1). Figure 2 shows two classrooms in the new physics building at the University of Georgia, one of which provides students with the more conventional pedestal-mounted seat with small tablet arm writing surface, and the other, special chairs which have almost table-size writing surfaces. Figure 3 shows similar chairs placed closer together to provide an almost continuous writing surface in a classroom in the new physics building at Colorado State University. Special tables and conventional chairs are used in the classrooms at Williams College where each table is shared by two students as shown in Figure 4a. Each table is also shared by two students in the classrooms in the new science building at Swarthmore College with, however, a somewhat different type of chair (Figure 5). Individual table-type writing surfaces are provided in the combination classroom-laboratory at the Air Force Academy, described in Chapter 7 (See Figure 14 in Chapter 7).

Although tablet arms and tables are designed to give the student a convenient and adequate area for writing, experience shows that before or after the class period, some students will lean against or sit upon these writing areas, and unless they are designed with sufficient strength to sustain the weight of a student, they will often suffer damage that is troublesome and expensive to

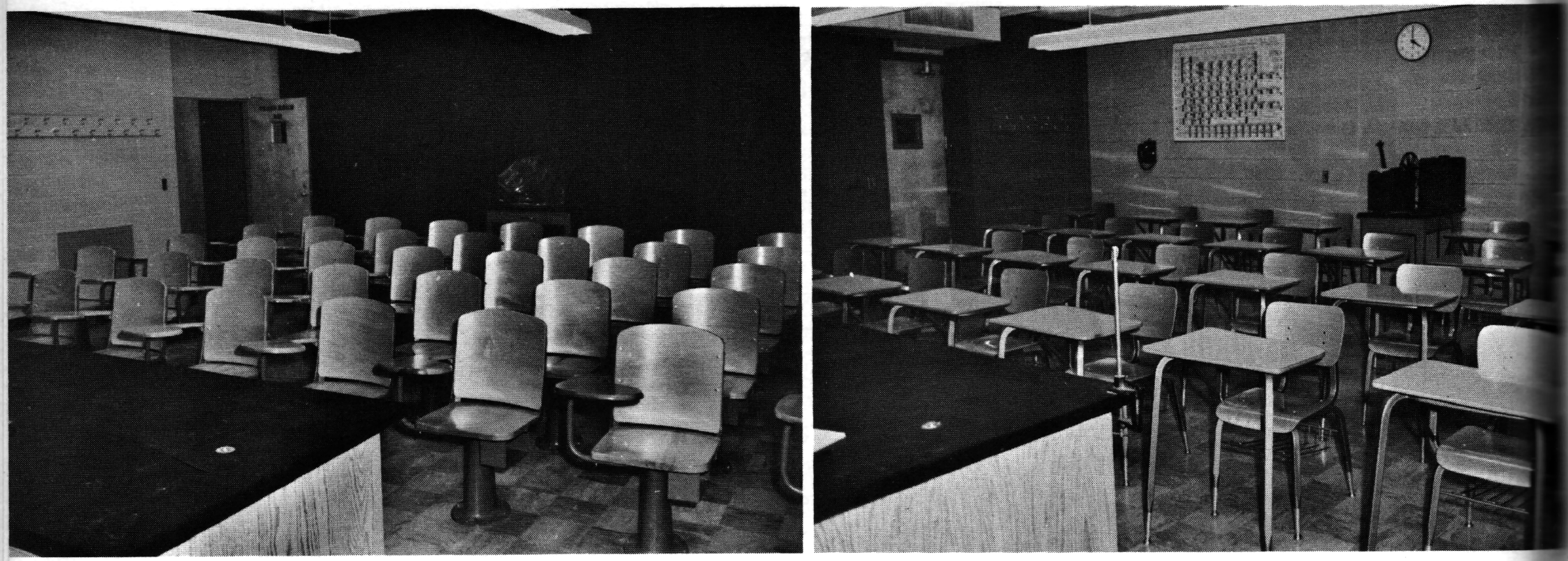
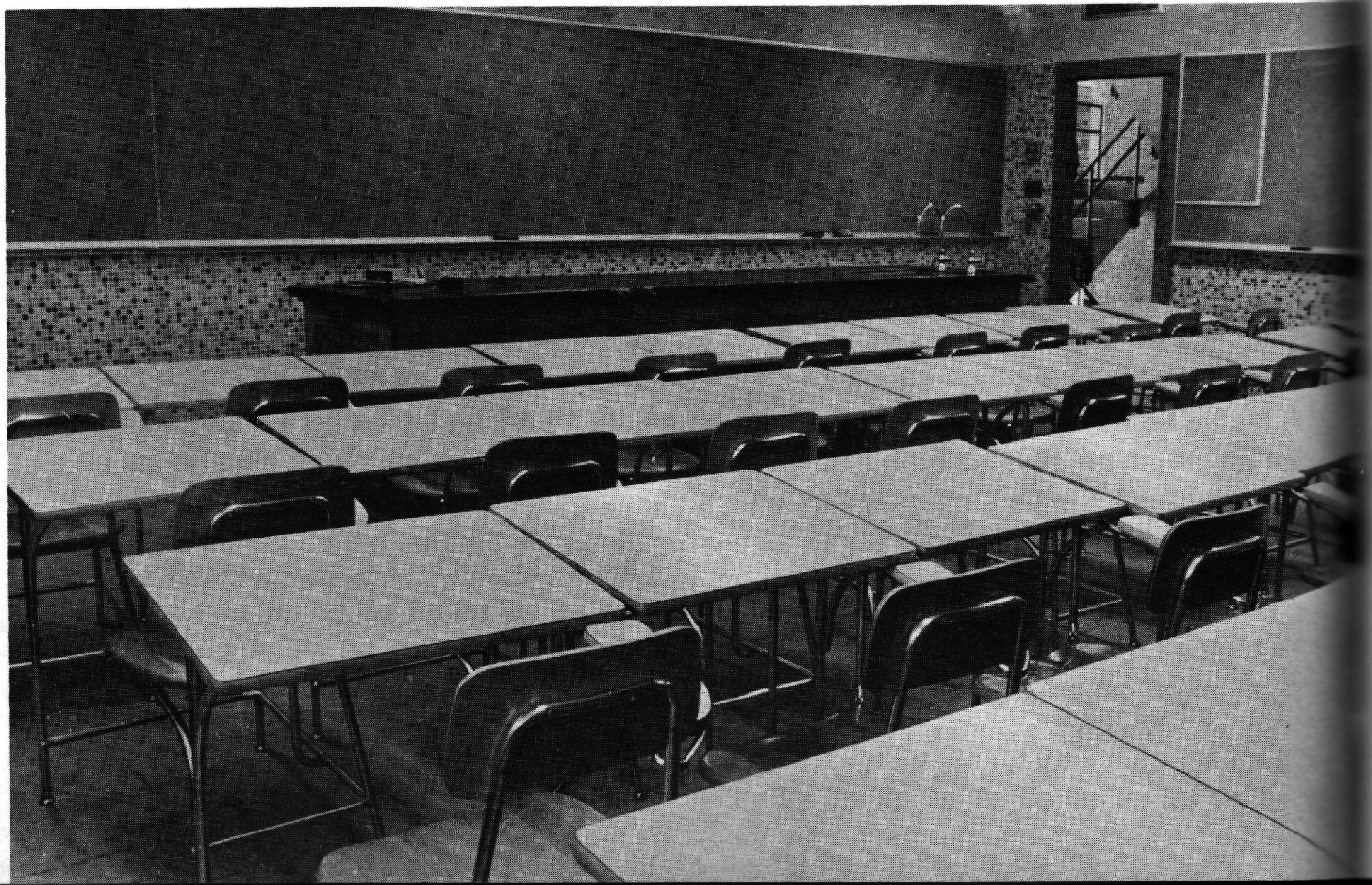


Figure 2. Two classrooms in the new physics building at the University of Georgia have different types of seating.

repair. Furthermore, writing upon or otherwise defacing the tablet area should be discouraged by using hard surface material, preferably one that is also resistant to the effects of burning cigarett butts which sometimes are carelessly laid on the arms.

Within limitations of a given room, seating orientation should be adopted so as to have the illumination from sources such as windows come from the left since most people are right-handed. If a room is designed to favor right-handed students, it will discriminate against left-handed ones, and experience indicates the desirability of making

Figure 3. Classroom in the physics wing, Engineering-Physics Building, Colorado State University.



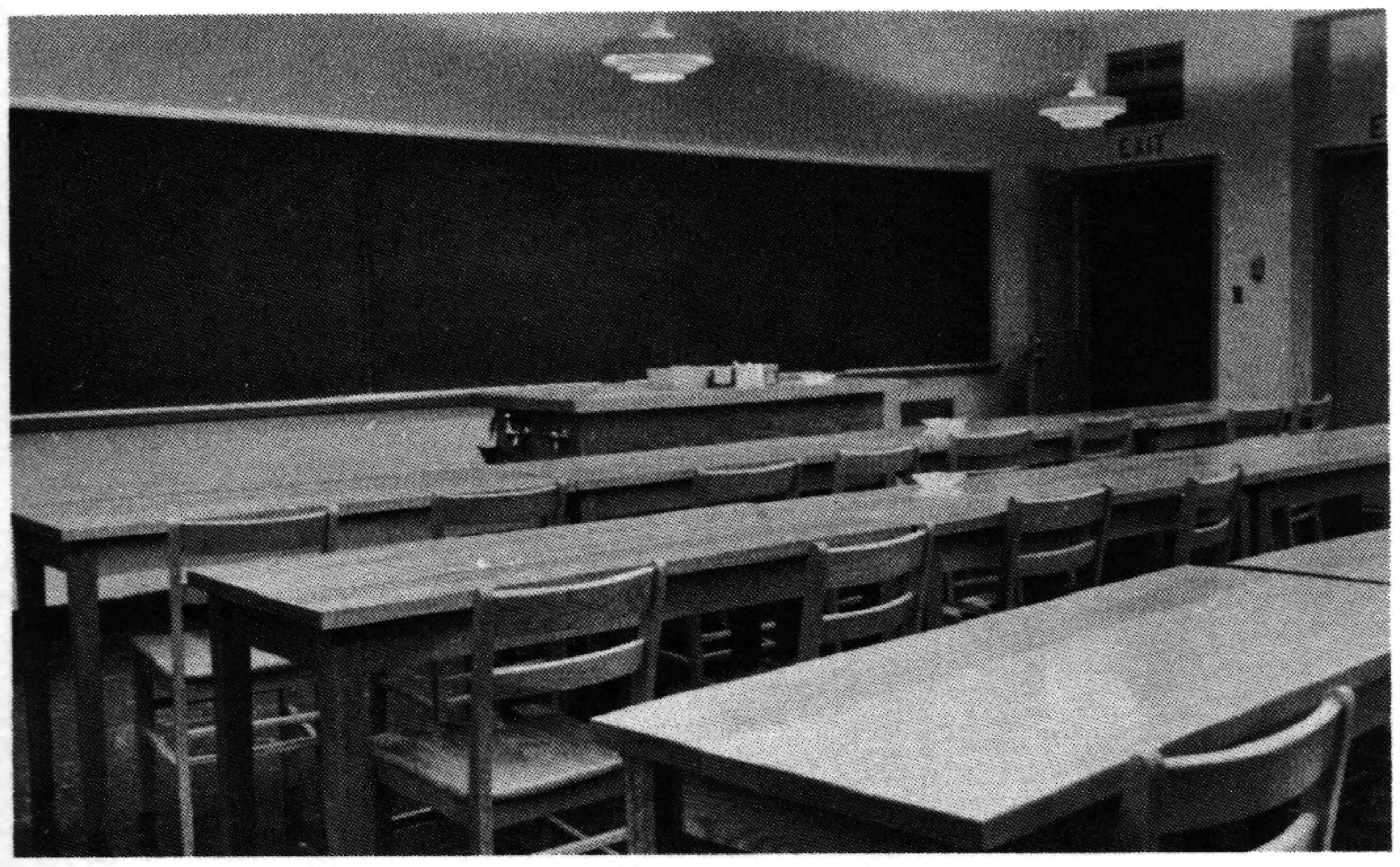
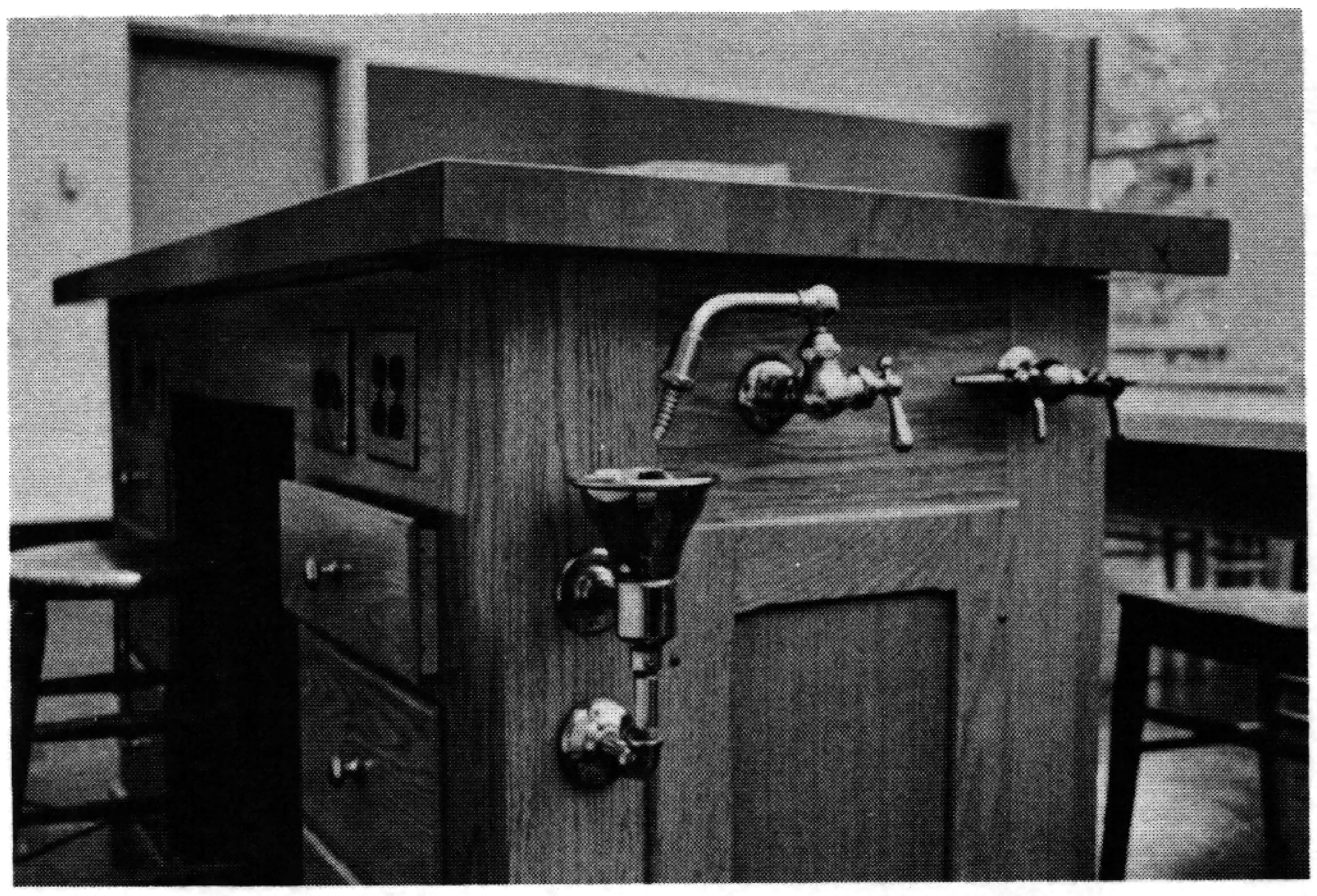


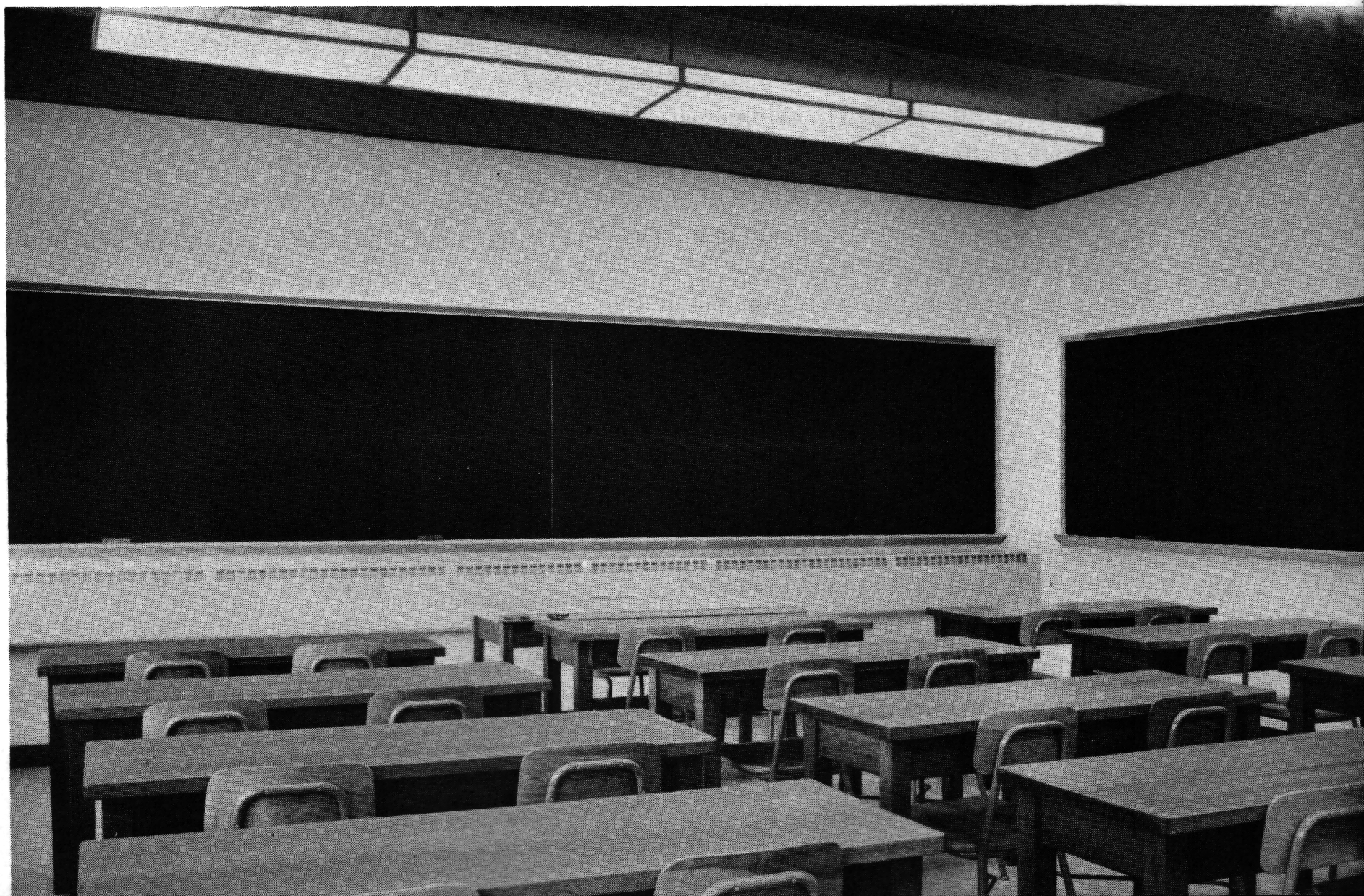
Figure 4a. Classroom in the remodelled physics building at Williams College has special tables, each serving two students.

Figure 4b. Photograph below shows lecture table with conventional utilities which serves as instructor's desk.



some concessions to the minority by installing a few seats with tablet arms for left-handed students. At one institution where an average of 11% of the students are left-handed, left-handed tablet arms were installed on approximately 8% of the chairs in the lecture room and classroom. However, we were

Figure 5. Classroom in the physics wing of the new science building at Swarthmore.



informed that usually less than half these seats are used. Apparently many left-handed students have learned to accommodate themselves to right-handed facilities and find the left-handed ones awkward to use.

Instructor's Desk

Normally a simple table and chair are adequate furniture for the instructor in a classroom that is used in the conventional way. However, at some institutions it is common practice to repeat in the recitation sections some of the demonstrations that were shown in the large lecture sections, and at most schools there is some need for one or more small rooms in which demonstrations can be shown to small groups of students. To meet this need it is desirable to equip at least one of the larger classrooms with the utilities necessary for these demonstrations. Figure 4 (b) shows the demonstration facilities in a classroom at Williams College—a small lecture table with gas, water, cup sink, and ac and dc outlets all placed unobtrusively beneath the overhanging table top and yet easily accessible to enable the instructor to perform a wide variety of demonstrations. At Colorado State University a somewhat larger demonstration table is installed in the classroom shown in Figure 3. When a room is designed to seat more than 40 or 50 students and is to be used to show demonstrations, consideration should be given to the advisability of either raising the demonstration table to a level higher than that of a writing table, or elevating the seats progressively toward the rear of the room—so that the demonstrations can be seen by everyone in the room. As a matter of fact, the seats are elevated (by a few inches per row) in the small 3-row classrooms at Burr Hall (Figure 1).

Chalkboards in Classrooms

Chalkboards are indispensable aids in physics teaching and their specifications and installation should ensure that they will serve their purpose satisfactorily for many years. Important factors to be considered are (1) the board height, (2) the amount of board space, and (3) the quality of the board. Most instructors prefer boards 4 feet high mounted solidly on the wall with the lower edges about 40 inches above floor level, and with a chalk and eraser ledge or trough mounted at the bottom of the board or recessed in the wall. Boards across the front wall of the classroom are essential, and to meet the needs of instructors who wish to send students to boards to work problems under supervision, all classrooms should have all available wall space covered with boards. A width of 4 feet provides an average comfortable working space per student, and if one half of a class of 30 students is assigned to the board at one time, 60 feet of chalkboard are required. It is often difficult to design a 25-by-20-foot room with more than this amount of board space unless there are no windows. In any case, it seems clear that classrooms should be equipped with all the boards that wall space permits, especially those rooms that are used by other departments such as mathematics. In one classroom we visited, in addition to fixed boards on three walls, an 8 foot section that could be rolled sideways was mounted in front of the chalkboard at the front of the room. Vertically movable multiple boards also offer the possibility of extra area; however most classrooms (unlike lecture rooms) have ceilings that are too low to permit the installation of this type. Furthermore, it is more expensive than the horizontal type.

Since classroom chalkboards are exposed to hard use, they should have good writing and erasing qualities and the writing on them should be easily visible. A discussion of chalkboard characteristics is given in Chapter 3.

The wall below the board is frequently soiled by students who, when facing away from the board, rest one foot against the wall leaving shoe marks that are often difficult to remove. To facilitate cleaning of these unsightly marks the wall surface should be made hard and smooth and preferably not light colored. The mottled tile wall shown in Figure 3 is easy to clean and also presents a pleasing appearance.

Visual Aids

Every classroom should have a projection screen and a projector mounting with electrical outlets so that slides or films can be shown readily. The convenience of a permanently installed roll-type screen encourages the use of audio-visual teaching aids, and some screens presently in use are recessed inconspicuously in the ceiling several inches in front of the front wall. Slide or moving picture projectors can be obtained from the departmental storeroom when needed or if duplication of equipment can be afforded, each room can have its own projector equipment stored in a cabinet with a lock. Sometimes a projector is fastened to a table but at institutions where vandalism is a problem this may not be feasible. At one institution projectors are fastened to a hinged table leaf that folds into a cabinet that can be locked. At another institution a projector at the back of the room is sometimes operated by remote control, starting and stopping from the front of the room.

Satisfactory projection usually requires a darkened room. The so-called "audio-visual" type venetian blinds with slats described in Chapter 3 are often adequate when they are installed with blackout channels on each side. Otherwise, light-proof shades with blackout channels can be made entirely satisfactory. However, wear and tear of shades of all kinds presents a troublesome maintenance problem and their design should anticipate hard use.

Charts and Notices

Every classroom should have some provision for hanging charts and posting notices. Permanent or semi-permanent charts can be conveniently suspended from metal channels that are either mounted upon or flush with the wall and run across the front of the room and along a side wall near the ceiling. Charts and even heavier items can also be suspended from aluminum brackets that are furnished to slide along the upper rail of the frame of many commercial chalkboards. Some commercial rails contain strips of cork that will take thumbtacks.

A small tackboard near the door at the front of the room will serve for posting newsworthy items and notices. A small tackboard appears to the right of the door in the classroom shown in Figure 3.

Returned Papers and Answers to Problems

The correct answers to examination problems and homework are frequently posted for the benefit of students. However, a more instructive procedure is to post not only the answers but the entire solution to each problem, logically presented and with adequate drawings. This requires more space than a small classroom bulletin board will allow. A number of institutions post solutions on a much larger bulletin board in the hallway, with successive sheets spread out to minimize student crowding. Narrow tables or shelves are placed beneath the bulletin boards for students to write upon and sometimes stools are provided for them to sit on while studying the solutions. At several institutions a special room is set aside to house special tables constructed similarly to that sketched in Figure 6—to increase the effec-

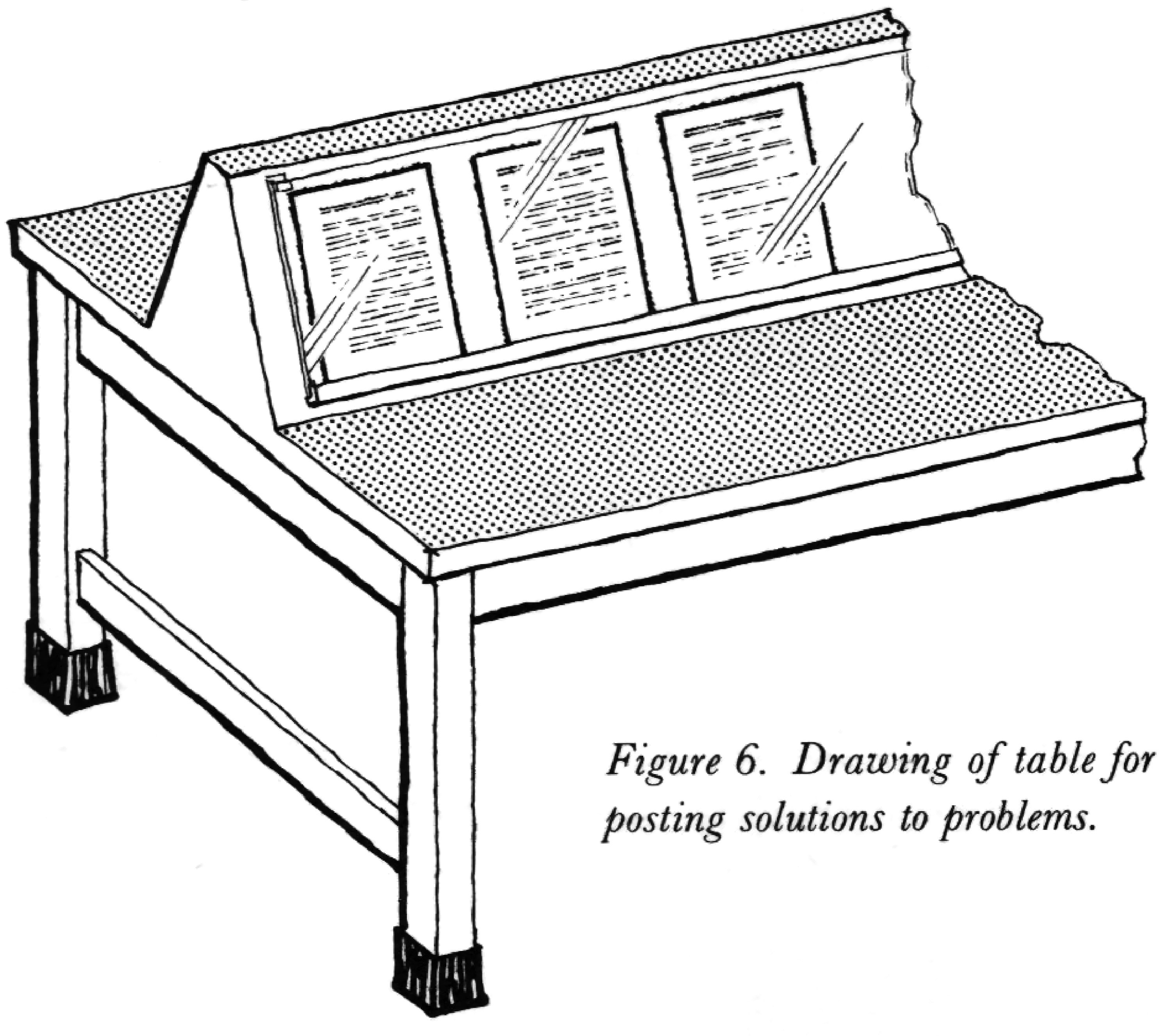


Figure 6. Drawing of table for posting solutions to problems.

tiveness of this adjunct to teaching. At most institutions, the sample problem sheets have to be placed behind locked glass doors for otherwise they disappear too frequently.

Outer Wraps and Extra Books

Adequate provision should be made for taking care of outer wraps and extra books in all classrooms. Most modern school chairs provide a shelf either beneath or to one side of the seat for books. These can be seen in some of the photographs in this chapter. But most classrooms fail to provide space for students' outer wraps, and as a result they go on the floor or are draped over the backs of chairs to the discomfort of their occupants. However, a number of classrooms in new buildings now provide built-in facilities or portable commercial metal racks with wire coat hangers. In either case, it is recommended that the coat hangers be simple hook type hangers which can be removed from the rack for hanging up one's coat. The problem of the disappearance of hangers can be solved by using special hangers which do not possess conventional hooks but which can be removed from the rack to simplify their use. Hangers of this kind are sketched in Chapter 3, Figure 14.

When a building is designed with a double corridor wall to provide riser space for mechanical and electrical utilities, much of this space frequently is unassigned. With careful design, a short section of this space can effectively be used in each classroom for either a built-in or commercial coat rack. The multiple use of such space is described in Chapter 3.

FLEXIBILITY

Reallocation of Rooms

Certain classrooms in the new physics building at Worcester Polytechnic Institute have the utilities stubbed in at the side wall and covered with a removable plate in case it should become necessary to use the room as a laboratory. At other institutions similar plans would make it possible to convert two adjacent classrooms into a general physics laboratory if the enrollment should so demand. Classrooms, after all, are easier to find elsewhere than laboratories and if necessary, they can even be used in another building; new laboratories are much more expensive to construct unless the required utilities are near at hand.

Combination Classroom and Laboratory

At a number of institutions the elementary laboratory doubles as laboratory and classroom. This use is discussed in some detail in the following chapter where Figure 14 and 15 show combination rooms at the Air Force Academy and at El Camino College.

Adaptation for TV

Several new physics buildings have been constructed with coaxial cables installed to each classroom, making connection either directly or through a central switchboard to the lecture room. This prepares the way to experiment with teaching techniques involving the use of closed circuit television by presenting lectures, demonstrations or experiments that originate elsewhere in the building, or by receiving educational programs directly from distant stations.

THE SEMINAR ROOM

Classrooms are frequently used as seminar rooms where small groups of students meet for informal discussions, usually with one or more faculty members. Coffee is frequently served to enhance the informality of the occasion. A social period is sometimes scheduled to precede a seminar meeting, and at this time more elaborate refreshments are usually served. Figure 7 shows how a kitchenette has been installed for this purpose in an alcove off the seminar room in the new

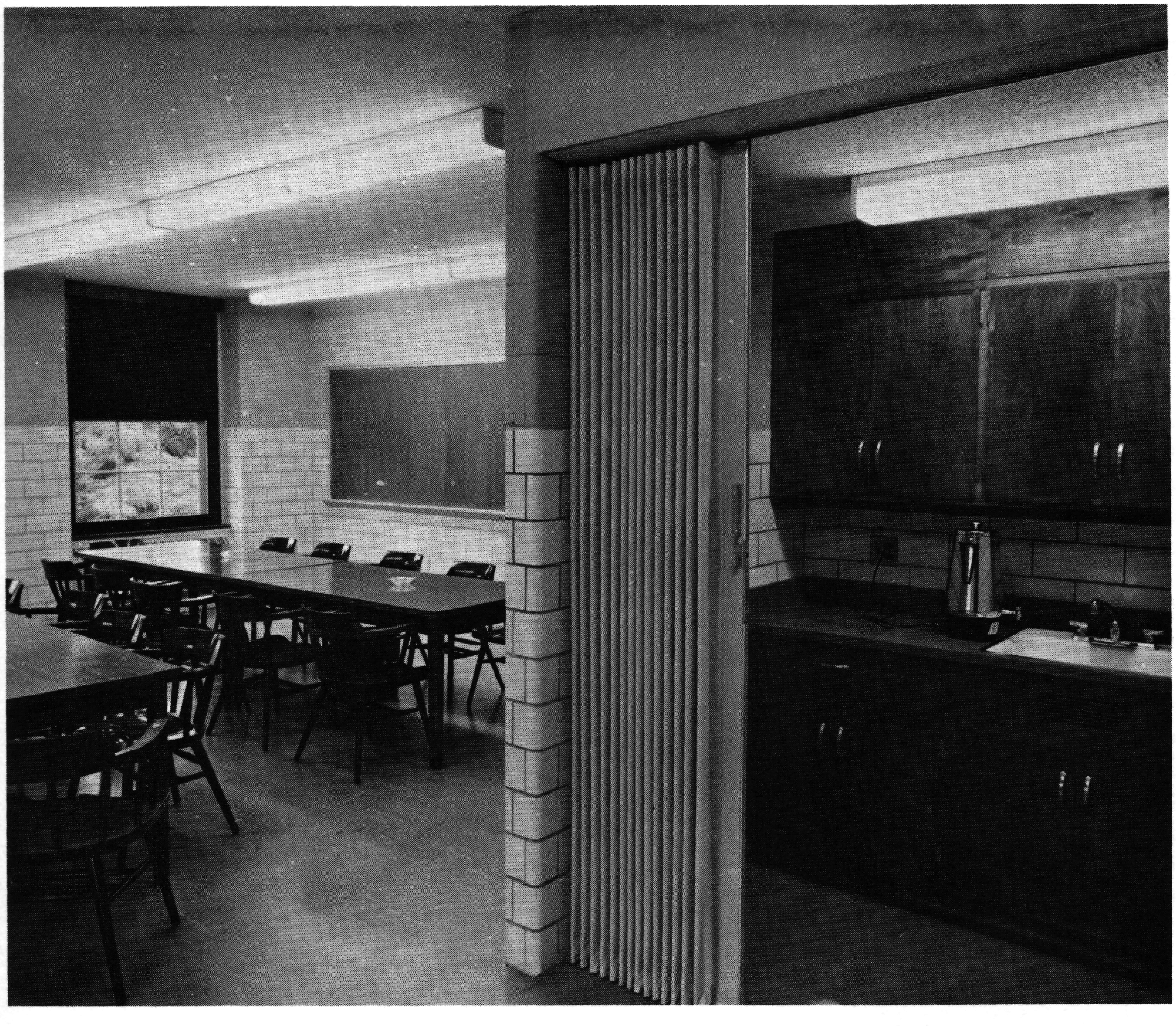


Figure 7. Seminar room in the new Olin Hall of Physics at Worcester Polytechnic Institute.

physics building at Worcester Institute of Technology. Note that it can be closed off from sight by means of a flexible partition.

The seating in seminar rooms may be the conventional classroom type. However, for small group discussions and for greater informality, seating around a table is to be preferred, as at Worcester (Figure 7).

7. Teaching Laboratories

INTRODUCTION

Elementary courses in physics are almost universally accompanied by laboratory work. Advanced laboratory work is also provided in connection with many advanced courses at the undergraduate level, although it is frequently optional. Advanced laboratory courses, such as Electrical Measurements, Electronics, Optics, and Modern Physics may be given without accompanying class work, and certain separate techniques courses are frequently offered at the graduate level. In a number of courses, mainly elementary courses for non-science students, experiments performed by the instructor as demonstrations are substituted for individual experiments on the part of the student. However, there has been no indication of a trend toward this method of teaching. One may assume that physics buildings will continue to require teaching laboratory facilities unless there is a drastic change in the nature of the physics curriculum.

THE ELEMENTARY LABORATORY

Location

A number of factors must be considered in determining where the elementary laboratories should be located in a physics building. In the first place, if a large number of students must be accommodated, several laboratory rooms are necessary and the task of distributing apparatus becomes significant. It is clear that the task will be aggravated unless the laboratories are all located on the same floor and as near the apparatus storeroom as possible. Since a considerable floor area must be set aside for these laboratories, they cannot be simply assigned left-over space. Furthermore, the problem of student traffic must be considered. Student density is usually less in the laboratory than in classrooms and lecture rooms; also, the laboratory period is at least two, and usually three, class periods in length. Area for area, there is thus less traffic associated with the teaching laboratories than with other teaching areas in the building. This suggests that these laboratories need not be located as close to the entrance to the building as classrooms and lecture rooms. They could be on an upper floor providing the stairway leads directly outside so that students do not need to pass through corridors in other areas of the building. Another factor that must be considered in the location of all laboratories is, of course, the cost of distributing utilities.

Space Requirements

Laboratory sections in elementary physics are usually small. The space provided for the laboratory work at some representative institutions is given in Table I. Individual laboratory rooms for single sections of from 16 to 30 students range in size from about

Table I. Space Provided for Elementary Laboratory Work at Selected Institutions

Institution	Elementary Laboratory Rooms					Work Stations
	No. of Rooms	Average Floor Area (Square Feet)	No. Students Per Room	No. Work Stations Per Room	Floor Area Per Student (Square Feet)	Table Top Area Per Student (Square Feet)
Calif., Univ. of (Berkeley)	2 2 2	1250 1700 2100	40* 40* 60**	20 20 30	31 42 35	11.0
Colorado, Univ. of	3	800	30	15	27	6.0
El Camino College	5	1500	30	15	50	7.5
Georgia, Univ. of	2 5	1400 675	32* 16	34 16	44 42	10 10
Illinois, Univ. of	10	1000	24	12	42	8.0
Iowa State Univ.	3	1000	20	10	50	10.5
Kan. State Teachers College	2	840	18	9	47	6.0
Kansas, Univ. of	4	1000	24	12	42	7.5
Louisville, Univ. of	4	750	24	24	31	7.2
Maryland, Univ. of	3	725	22	12	33	6.0
Michigan, Univ. of	4	900	20	10	45	8.0
Minnesota, Univ. of	12	700	16	8	44	5.0
State Univ. of Iowa	4	900	18	9	50	6.0
Worcester Poly. Tech	2	1100	24	24	46	15.0

* Two laboratory sections
** Three sections

700 to 1100 square feet, and thus provide an area which averages about 40 square feet per student. In general, this amount of space seems adequate. (The entry for El Camino College is for a combination classroom and laboratory, and thus the room is larger than most.)

At institutions that handle a large number of students, several laboratories of this size are usually provided rather than a smaller number of larger laboratories. Notice that 12 laboratories of 700 square feet each are provided at the University of Minnesota, with each laboratory accommodating only 16 students. We have seen a few laboratories where as many as 60 students are handled in a single room; however, the space required per student remains about the same. Some have expressed their dissatisfaction with multiple section laboratories because of the noise and confusion that can develop. Others seem satisfied with large laboratory rooms.

Table I also gives the area of the top of the work table provided for each student in the elementary laboratories at the institutions named. The area varies from about 6 to 15 square feet with the median a little over 7 square feet per student. These figures do not reflect the fact that in a few cases the staff expressed the wish that their tables might have been wider or longer.

Utilities

Students in the elementary laboratory usually work together in pairs at a "station"; a laboratory with 10 stations normally accommodates 20 students. A variety of mechanical and electrical services must be available in the laboratory though not all services need be supplied at every station.

Table II lists these services and indicates the relative number of elementary laboratories in which each service is provided (a) at some point in the laboratory and (b) at individual work stations. It will be noted that the only services that are provided in essentially all laboratories are cold water and drain, gas, and ac at 120 volts. Furthermore, the only one of these that is quite consistently distributed to individual work stations is 120 volts ac although gas is also almost as widely distributed. Each work station should have at least four ac outlets.

When an institution has several elementary laboratory rooms, one may be reserved for the experiments associated with the work of a particular semester. All rooms, therefore, do not require the same services for laboratory work. A "dry" laboratory is adequate for experiments in electricity and mechanics, while water is required for certain experiments in heat. The expense involved in installing sinks at each station, together with the fact that they are in the way when not needed, has led some laboratories to provide them only at every other station. The staff in these laboratories finds this number quite sufficient even for experiments in heat providing that experiments are scheduled so that not all those underway at any one time require running water. Furthermore, where a large sink is available elsewhere in the laboratory, a small cup sink is found to be quite adequate at the individual stations which require water.

Many physics experiments require a source of direct current, and for this a number of laboratories rely entirely on local portable batteries. Storage cells are used when high current or constant voltage is required, though dry cells are preferred for most purposes because storage cells require constant attention and are messy to handle. Other laboratories use the 120-volt dc house generator in which case one or two polarized outlets that connect directly to the generator are usually provided at each station. Most physics laboratories, however, are equipped with some sort of a central dc distribution system (it may supply only the elementary laboratory), and at least one pair of free lines is provided at each station—lines which can be connected either to a switchboard within the laboratory or directly to the control switchboard for the building, depending on how elaborate the system is. (See the discussion of central systems in Chapter 3.)

Table II. Services Provided in the Elementary Laboratory

	Relative Number of Elementary Laboratories in which each Service is Provided									
	(a) at some point in the laboratory					(b) at individual work stations				
Services (approximate percent)	100%	75	50	25	0	100%	75	50	25	0
Mechanical Services: sink with cold water	X							X		
hot water			X							X
steam					X					X
gas	X					X				
compressed air		X							X	
vacuum					X					X
Electrical Services: ac 120v 60c single-phase	X					X				
ac 60c three-phase					X					X
dc house generator		X						X		
free lines to switchboard		X					X			

Fuses or circuit breakers for electric service and shut-off valves for water and gas should be conveniently located and properly labelled. Circuit breakers are currently more widely used than fuses for overload protection because of their greater convenience. Where the maximum load is known, circuit breakers may be best. Where the load is variable, fuses may be preferred; they can easily be changed to provide the desired overload protection. Some instructors prefer fuses simply because of the time required of a student to replace a fuse—the student has more time to think about what caused the interruption of current. It is just too easy to restore power with a circuit breaker. (Incidentally, it is for this reason that where circuit breakers are used, some prefer the thermal to the magnetic type of breaker; after a thermal type of circuit breaker has been tripped it must be allowed to cool before it can be reset.) Whatever protective devices are selected should be mounted in a panel which is located nearby—either in the adjacent corridor or preferably within the laboratory itself. Where free lines from a central distribution system (or an individual laboratory system) are installed, the panel is usually located within the laboratory although occasionally it is mounted in a locked box in the adjacent corridor. An individual circuit breaker or fuse is usually provided for each free line.

Separate cut-off valves for water and for gas should also be provided for each laboratory. It should not be necessary to turn off the gas or the water to the entire building—or even to one side of it—when an emergency arises in one laboratory. Furthermore gas cocks should have handles rather than knobs to provide visual on-off indication.

Illumination

Most new physics buildings today rely on artificial sources, principally fluorescent lamps, for lighting their laboratories. The level of illumination at table top height is generally in the neighborhood of 40 to 50 foot candles. This level is believed to be quite adequate for most laboratory work even though it is less than the 70 foot candles recommended by the Society of Illuminating Engineers for reading pencil writing. Supplementary portable lamps are usually available for making observations which require more localized light. Light fixtures should be near the ceiling to provide adequate clearance for tall apparatus. Furthermore, fixtures should have low surface brightness both for eye ease when viewed directly and to minimize glare from shiny surfaces. (See Chapter 3.)

Windows in a laboratory are of secondary importance in providing light and, as a matter of fact, may interfere with the effective operation of the laboratory. Large windows frequently have been criticized for taking up too much wall space—space which otherwise could have been used for mounting apparatus. The windows in the laboratories in the new physics building at Pomona College are relatively short with sills about 7 feet off the floor (Figure 11). This not only provides more wall space used in part for chalkboards at Pomona but also minimizes the number of unwanted reflections which may be bothersome in some experiments. Figure 15 shows that the added wall space gained from high windows is also well utilized in the laboratory at El Camino College.

Windows must occasionally be darkened for certain laboratory experiments in physics. Opaque roll shades which are properly baffled around all four sides provide quite satisfactory room darkening. Many instructors find that the partial darkening that can be provided by ordinary venetian blinds is adequate for elementary laboratory work. Others desire a darker laboratory and further steps must be taken, especially if the laboratory is on the sunny side of the building. At El Camino College the venetian blinds are supplemented by draperies that can be drawn when better darkening is required. (See Figure 15). So-called "audio-visual" venetian blinds which are now available from several manufacturers produce quite adequate darkening when properly installed. (See discussion in Chapter 3).

Each window in the new physical science building at Kansas State Teachers College is equipped with external, horizontal aluminum louvers that can be adjusted from the inside. (Figure 9; see also the photograph of the building accompanying the floor plans in Chapter 4). The staff finds these louvers are quite satisfactory for darkening their elementary laboratories.

Laboratory Layout

As noted earlier, a typical elementary laboratory is designed to accommodate 24 students, and the students usually work together in pairs. Twelve work stations are therefore required. To provide the necessary electrical and mechanical services at each station and to make it possible for as many as 24 students to work at the same time without interfering with each other, the laboratory must be laid out in an orderly fashion.

The arrangement adopted normally follows one of two general patterns: stations may be arrayed either throughout the center or around the perimeter of the room. Each arrangement has its advocates. A combination of the two patterns may be used in a laboratory designed to accommodate a larger number of students.

In planning the layout of a laboratory it is helpful to use cardboard templates to represent the furniture, and move them about on a scale drawing of the laboratory room made to the same scale, say 4 feet to the inch. One can thereby study how tables of different size can best be fitted into the room and determine the most desirable layout for the furniture that is selected. Or, alternatively, one can determine the shape and size of the laboratory room that will best fit the furniture layout one desires to use. This study can influence the selection of the building module and therefore must be done in the early stages of planning before the module has been frozen.

Three somewhat typical elementary laboratory layouts are given in Figure 1. All three schemes require essentially the same size room and differ principally in the location of student work stations and in the method of providing services. The other features have been kept the same. These include: a supplementary work bench and general wash-up sink at one end of the laboratory; a coat rack and a book rack (for laboratory notebooks and reports as well as for books) near the corridor door; a chalkboard and a bulletin board on the front wall; an instructor's desk and chair; and a clock. Two metal channels for hanging charts and experimental equipment run around the walls of the rooms. Frequently used apparatus can be stored in cabinets under the bench at the back of the laboratory, and in supplementary wall cabinets which can be mounted above the bench. The adjacent storeroom houses most of the experimental apparatus and may also serve a second laboratory on the other side of the storeroom. The door to the storeroom is located out of the line of student traffic. Where the policy of the department is to check out apparatus to students, a Dutch door or a service window can be used.

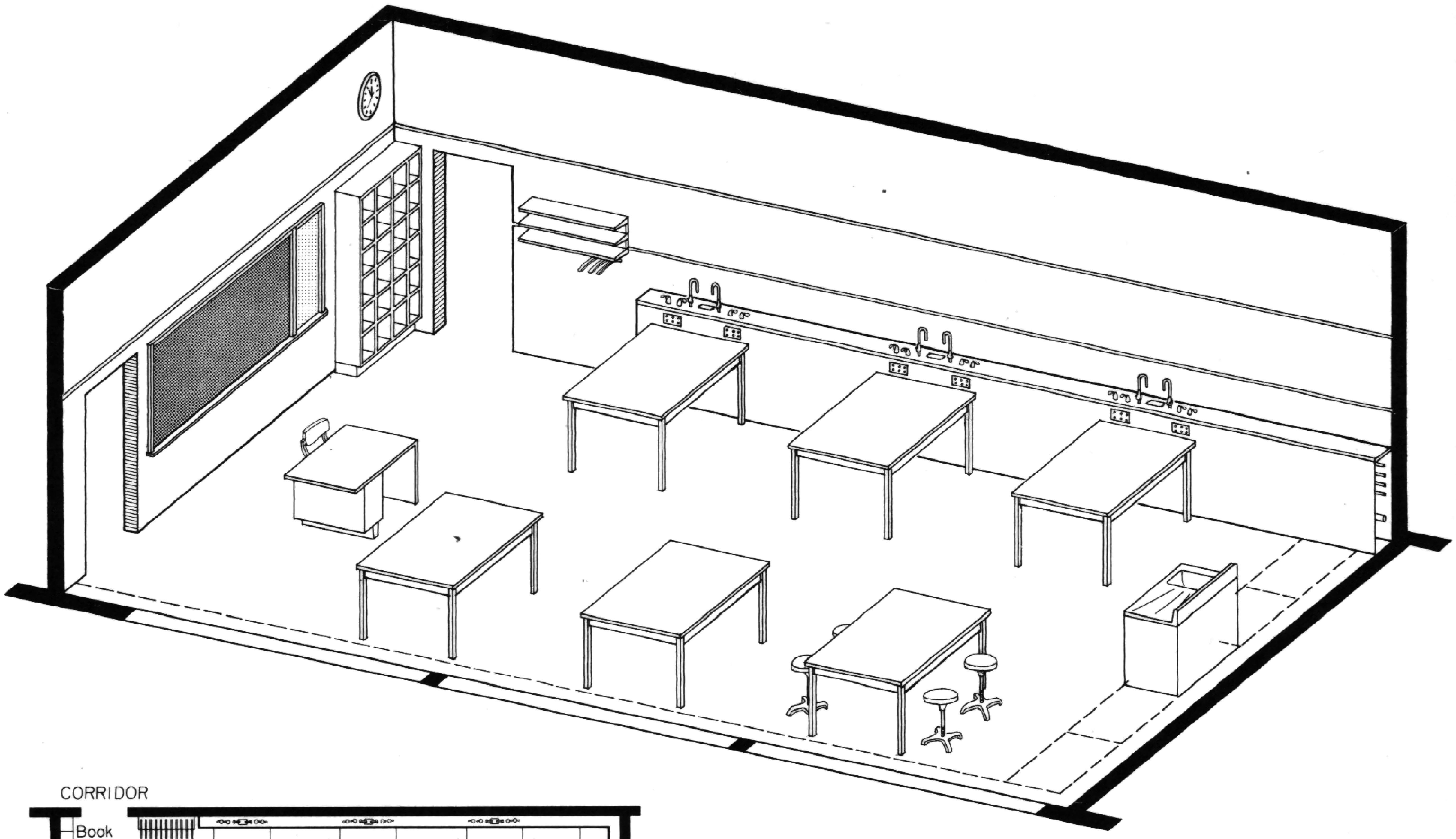
Each of the three laboratories accommodates the same number of students and has about the same floor area—about 900 square feet for 24 students; and the work space per student is about the same in each laboratory—about 7 square feet of table top area per student.

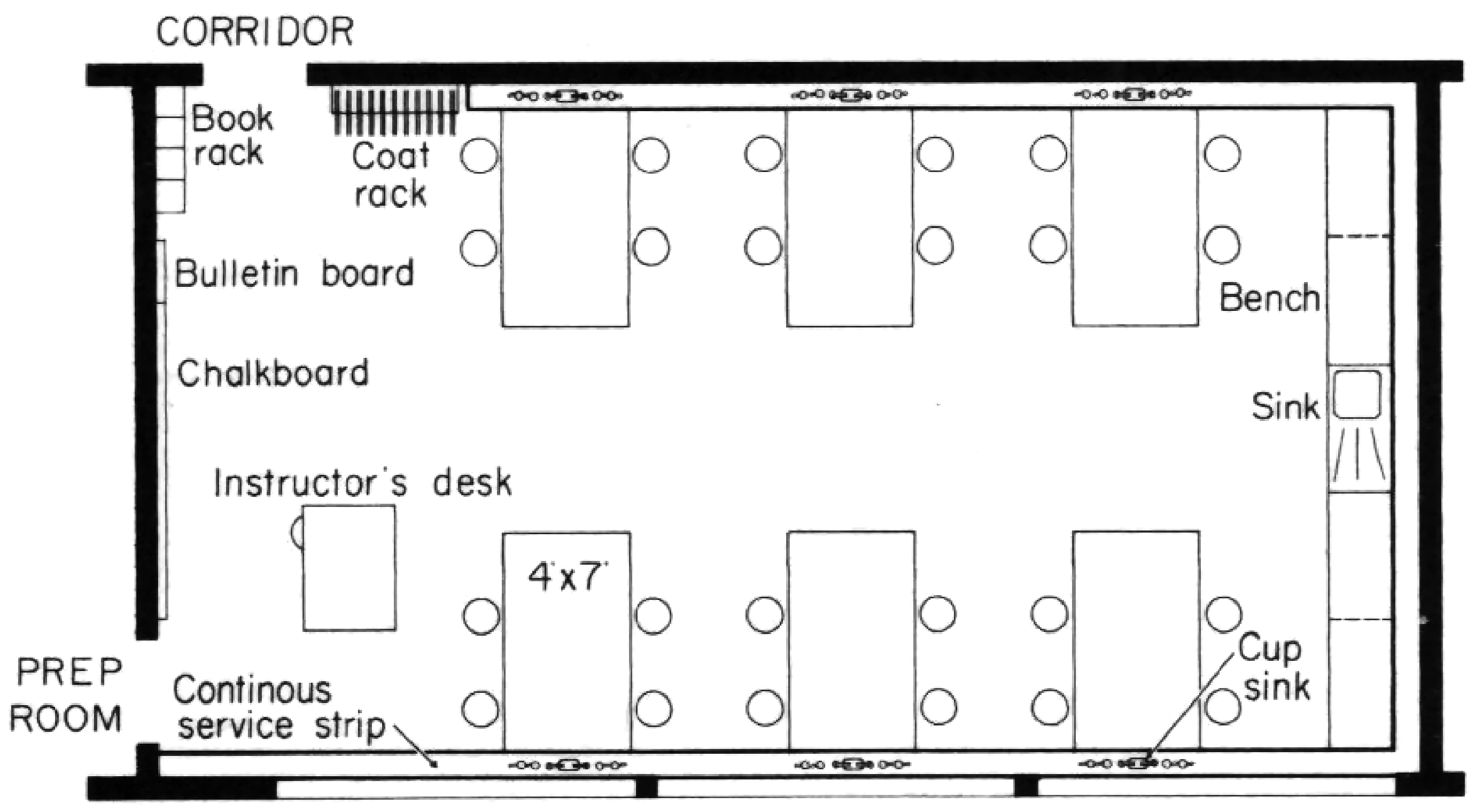
The tables are arranged along the side walls of the laboratory in Scheme A, and utilities are provided from a so-called service "island" which runs around three walls of the laboratory. The pipe and conduit for the utilities are enclosed within the service island. A cup sink with cold water and stopcocks for gas (and compressed air if desired) are mounted on the top of the service island, and electrical outlets for both ac and dc are on panels on the side of the island at each station.

In Scheme B, the tables have been moved to the center of the room and each station gets its utilities from one of three separate service islands. Each service island has electrical outlets for both ac and dc mounted on panels on its sides and a rectangular sink with running water and outlets for gas and air are mounted on the top of each island. The islands are the same height as the tables so that additional work space is available when flush covers are placed over the sinks. A clearer work area is provided if the stopcocks are mounted on the sides of the island and if the gooseneck water outlets are mounted inside the sink and can swivel down within the sink when not in use.

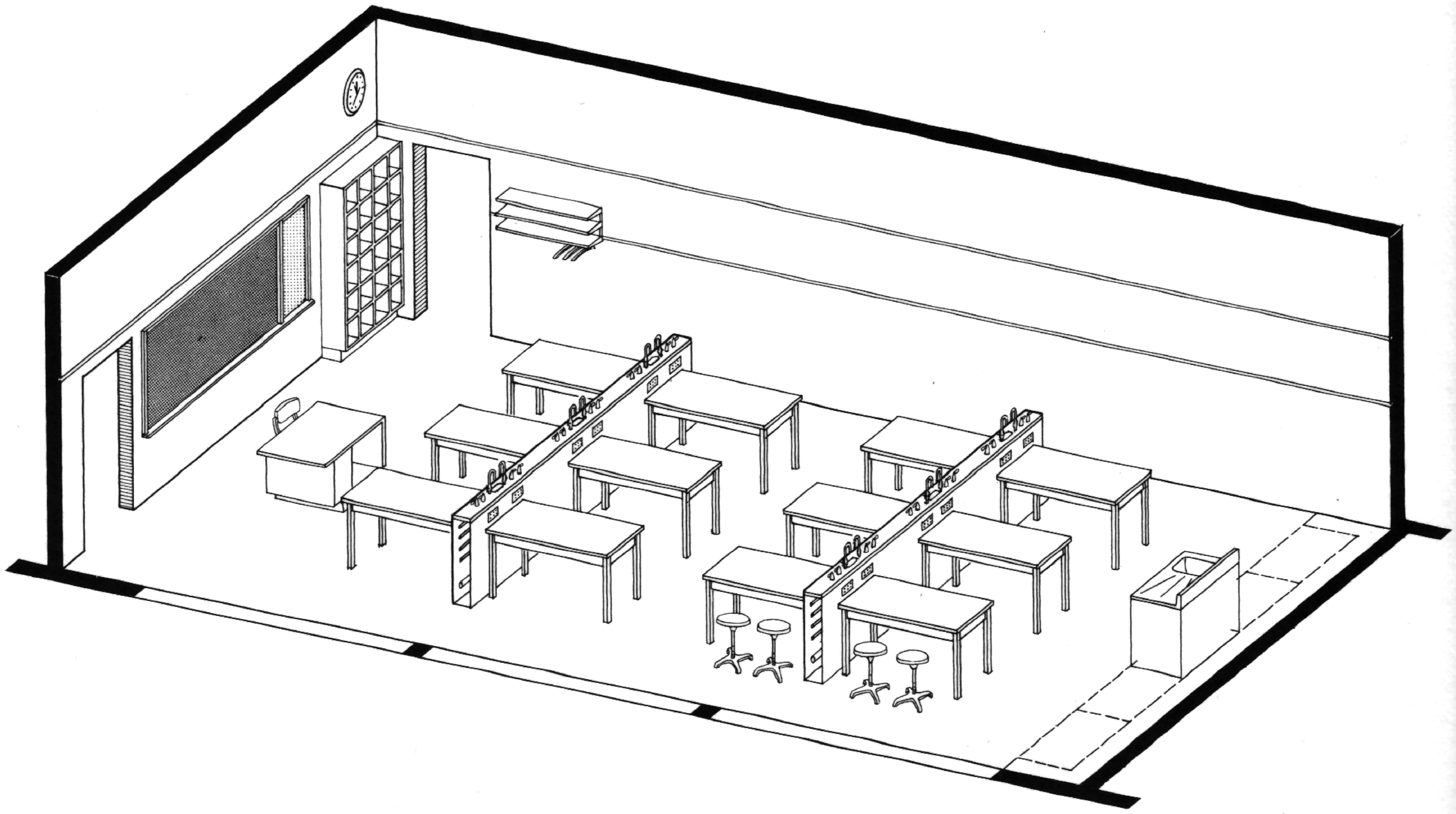
Each pair of students is provided with a single table in Scheme C and services are provided by two long free-standing service islands. Cup sinks and outlets for air and gas are on top of the islands, and electric outlets for both ac and dc are on the sides adjacent to each table, somewhat as in Scheme A. The length of table frontage available to each student is somewhat less than in Schemes A and B; however, this is balanced by the possibility of using both sides of the table when needed.

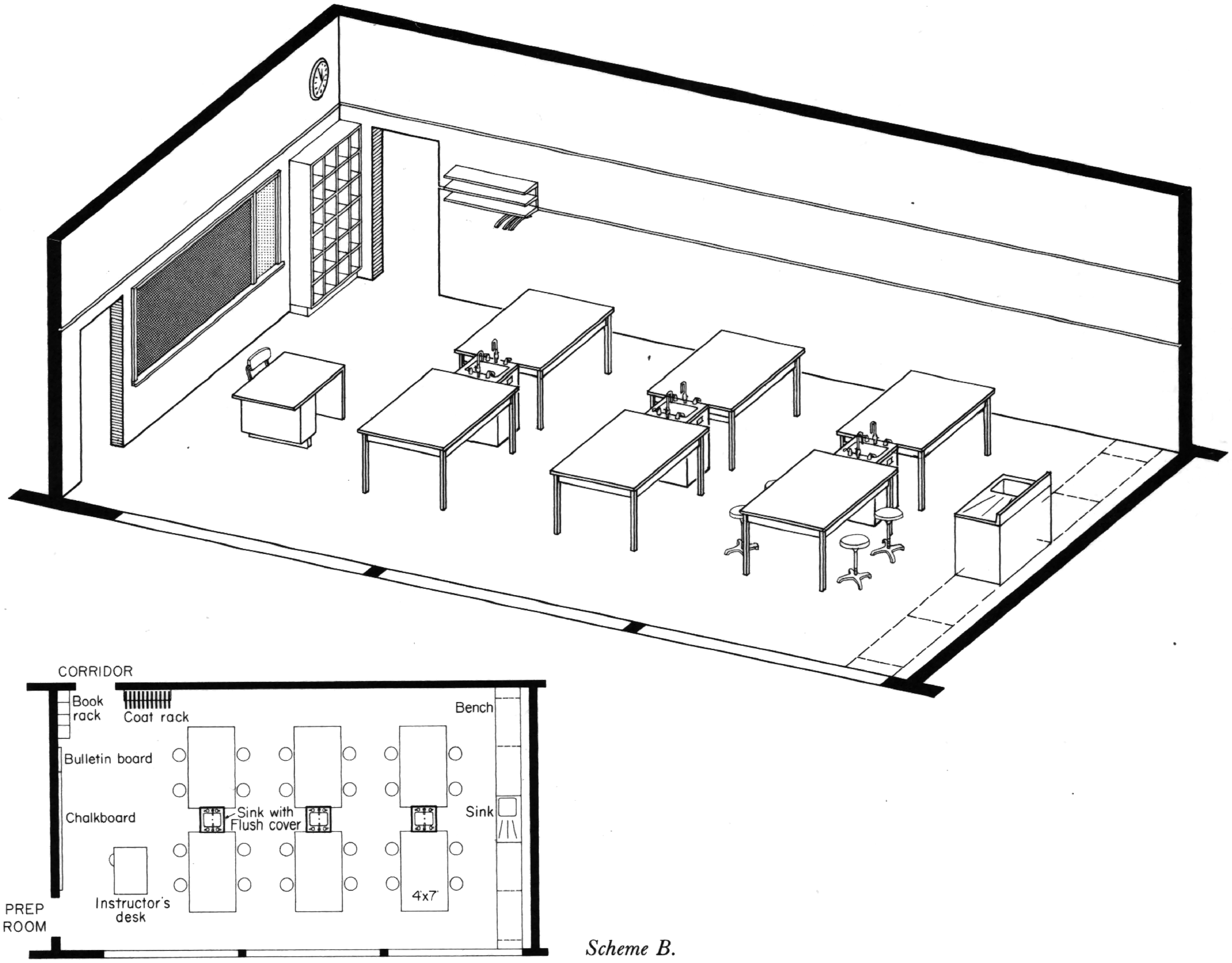
Note that where students work back to back as in Schemes A and B, a space of at least 5 feet should be left between tables to minimize the interference between adjacent stations, while only about 3½ feet are needed where only two students are working between tables as in Scheme C.



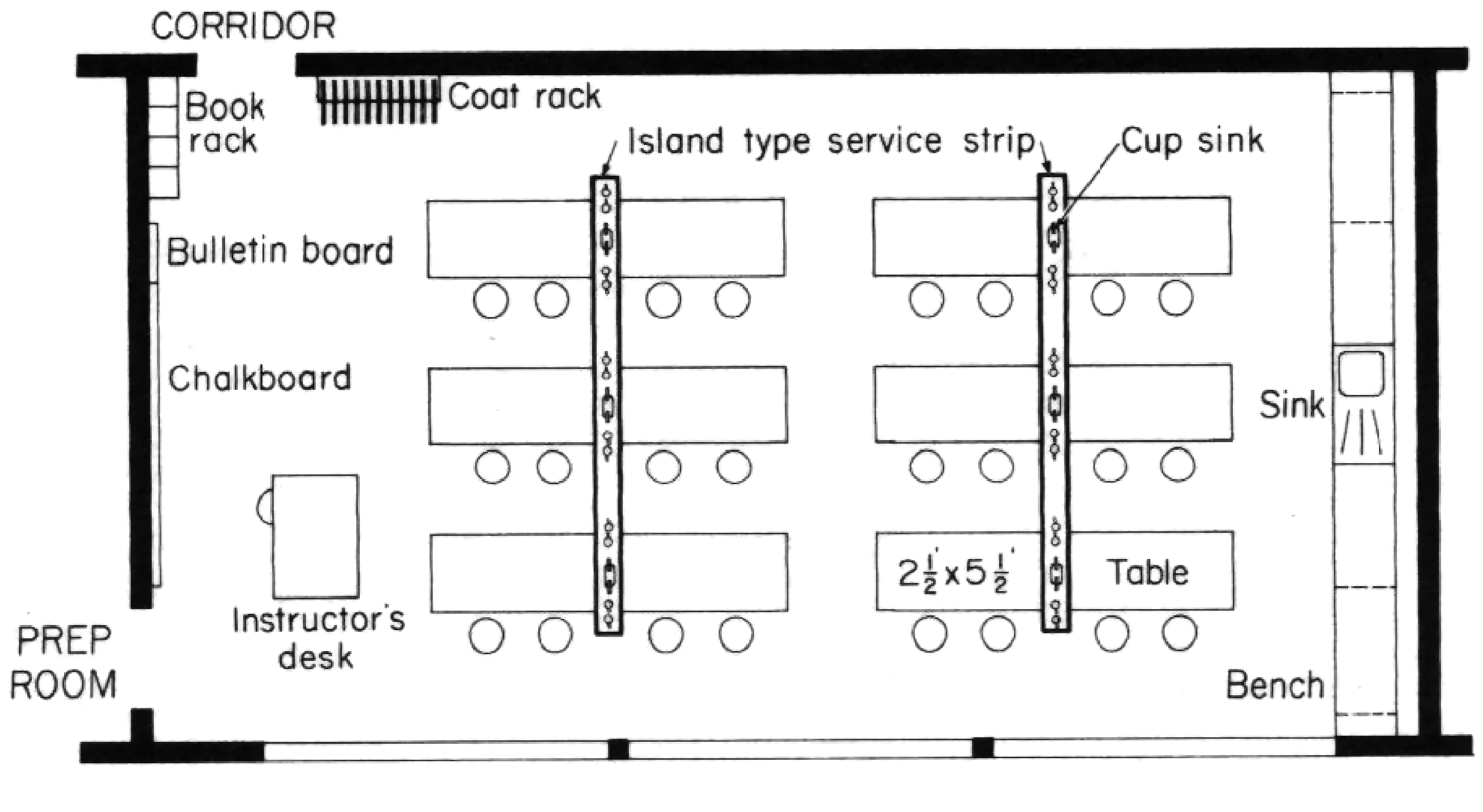

CORRIDOR
Book rack
Coat rack
Bulletin board
Chalkboard
Instructor's desk
4'x7'
Bench
Sink
Cup sink
PREP ROOM
Continous service strip

Scheme A.




CORRIDOR
Book rack
Coat rack
Bench
Bulletin board
Chalkboard
Sink with Flush cover
Sink
4'x7'
Instructor's desk
PREP ROOM

Scheme B.


CORRIDOR
Book rack
Coat rack
Island type service strip
Cup sink
Bulletin board
Chalkboard
Sink
2½'x5½'
Table
Instructor's desk
PREP ROOM
Bench

Scheme C.

Figure 1. Three typical elementary laboratory layouts, differing principally in location of student work stations and in method of providing services:

Scheme	*A*	*B*	*C*
Room Size (Feet)	*22 x 40*	*22 x 40*	*22 x 42*
Student Capacity	*24*	*24*	*24*
Work Space Per Student (Square Feet)	*7.0*	*7.0*	*6.9*
Table Frontage Per Student (Feet)	*3.5*	*3.5*	*2.75*

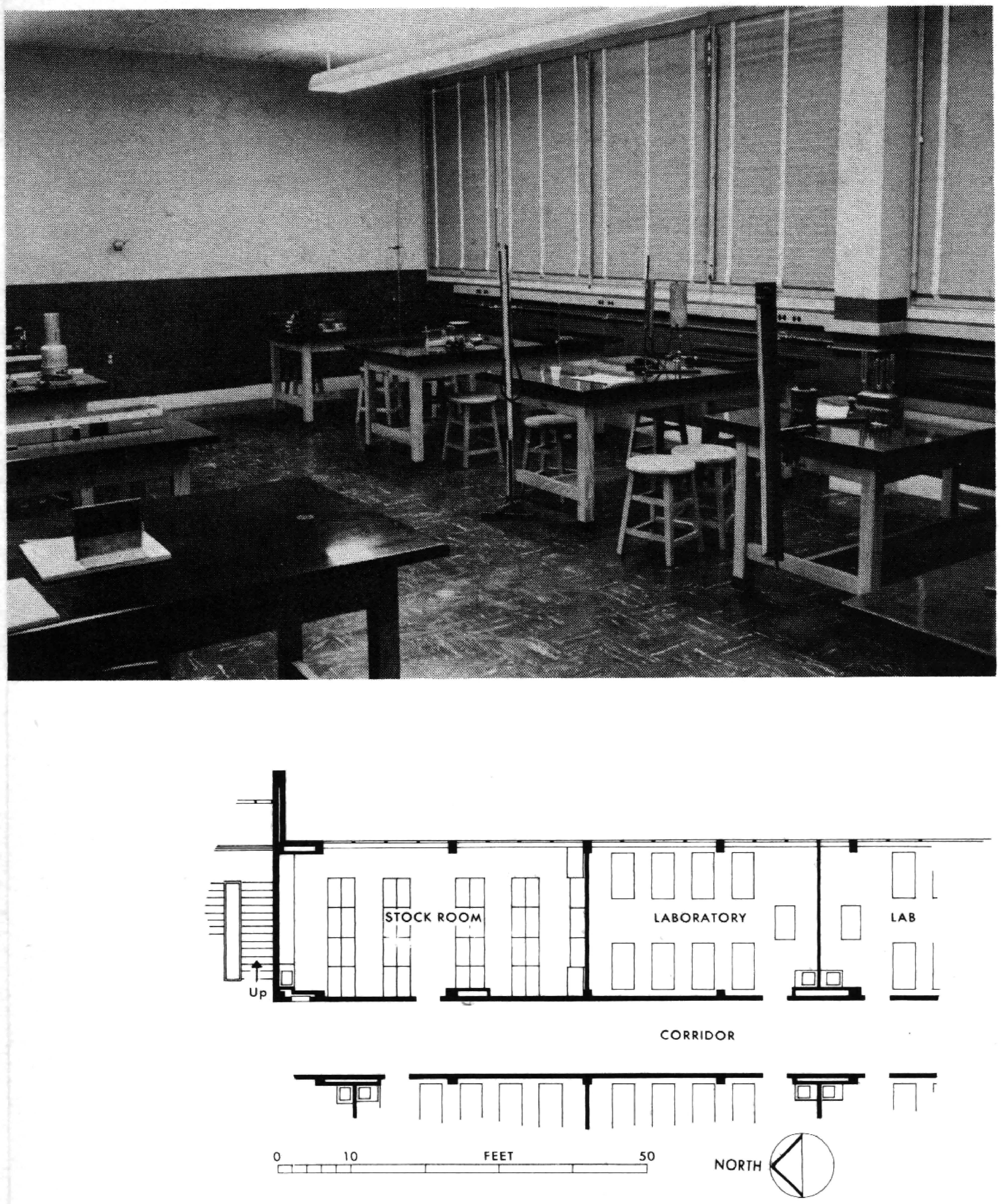


Figure 2. One of nine elementary physics laboratories at the University of Florida. (See Figure 3, Chapter 4.) Note the perimeter arrangement of tables with utilities provided at wall.

The accompanying photographs and floor plans for existing elementary laboratories have been selected to illustrate these schemes and variations on them.

The laboratory stations in the new physics building at the University of Florida are distributed along the side walls of the laboratory in a manner similar to Scheme A. Eight tables (each 6 by 3 by 2½ feet) accommodate 16 students in each of nine laboratories as shown in Figure 2. Gas and air are carried to individual stations by exposed pipes supported on the side walls. (Local code required gas pipes to remain in the open.) Outlets for ac and dc are in strip molding which is also attached to the side walls. Direct current for the teaching laboratories is supplied from a distribution board (and battery bank) which is separate from the system used for the rest of the building. Water for the laboratory is available at a stone sink in the front corner of the laboratory but not at individual stations. A table and chair for the instructor (plus chair-height stools for the students) complete the furniture. A single large storeroom serves to store the apparatus for nine elementary laboratories, all equipped alike.

The photograph of Figure 3 shows a similar array of tables in one of the elementary laboratories in the new addition to the physics building at the University of Texas. Pipes and conduit for services have been enclosed within a service island the same height as the tables, but otherwise similar to scheme A of Figure 1. All utilities—stopcocks for gas and separate turrets for ac and dc—are available at the top of the service island at each station. All dc outlets are on the same circuit which terminates at a panel on the instructor's desk where a heavy duty battery or rectifier can provide voltages to supplement the portable batteries used at student stations.

A similar layout of furniture is used in each of the two elementary laboratories in the new physics building at Catholic University of America. Twelve movable tables (each 32 inches by 6 feet by 37 inches) accommodate 24 students. The tables are arrayed along the side walls (Fig. 4) where services are available from outlets which are installed at intervals in the wall—water at simple metal funnel sinks, gas, 120-volt 60-cycle ac and 120-volt dc from the house generator. Portable batteries and rectifiers are used for low voltage work, the staff having decided to omit the installation of a central dc distribution system in the building. Note the fire extinguishers mounted on the front wall of the laboratory.

Scheme B of Fig. 1 is illustrated by the layout adopted for the elementary labora-

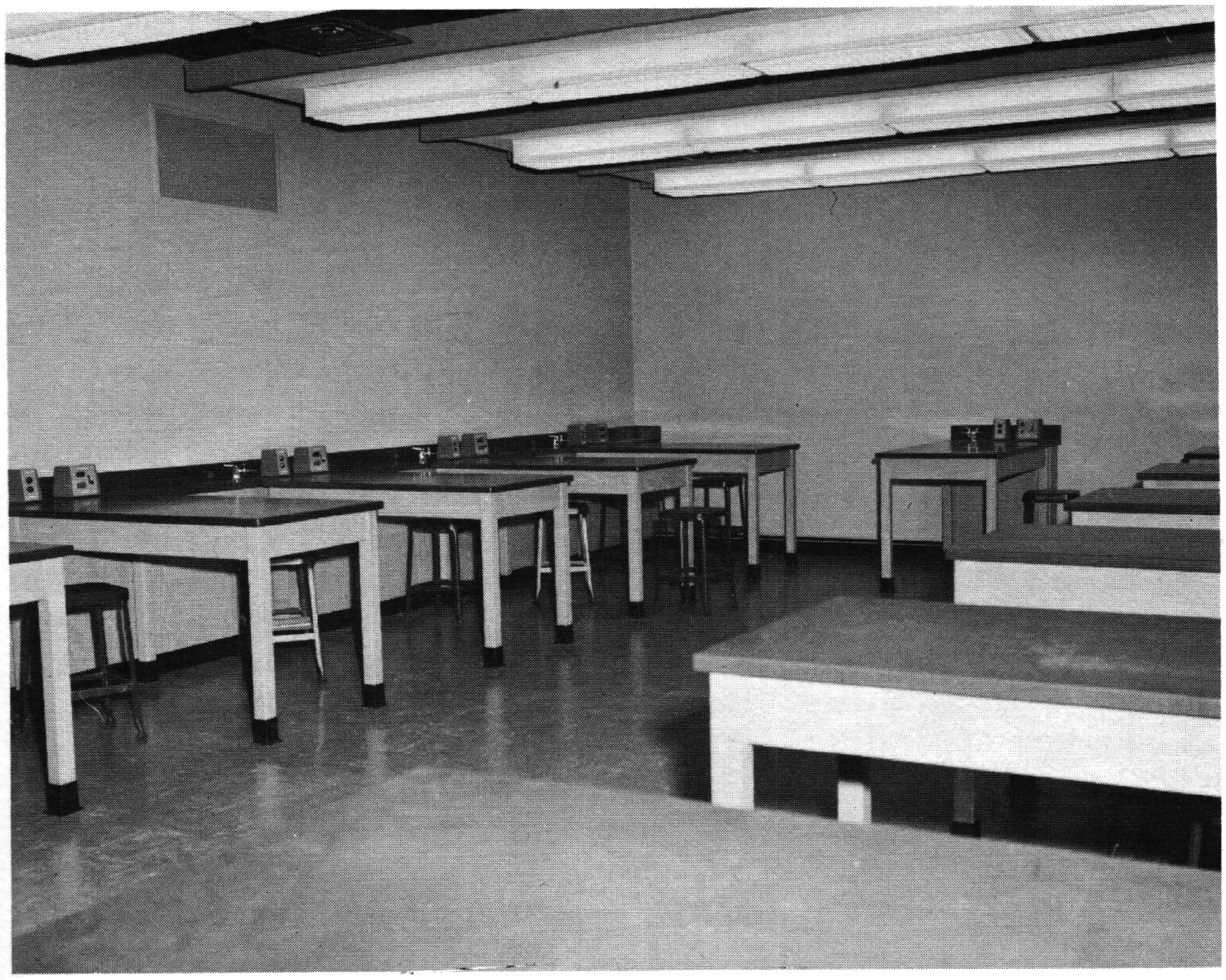
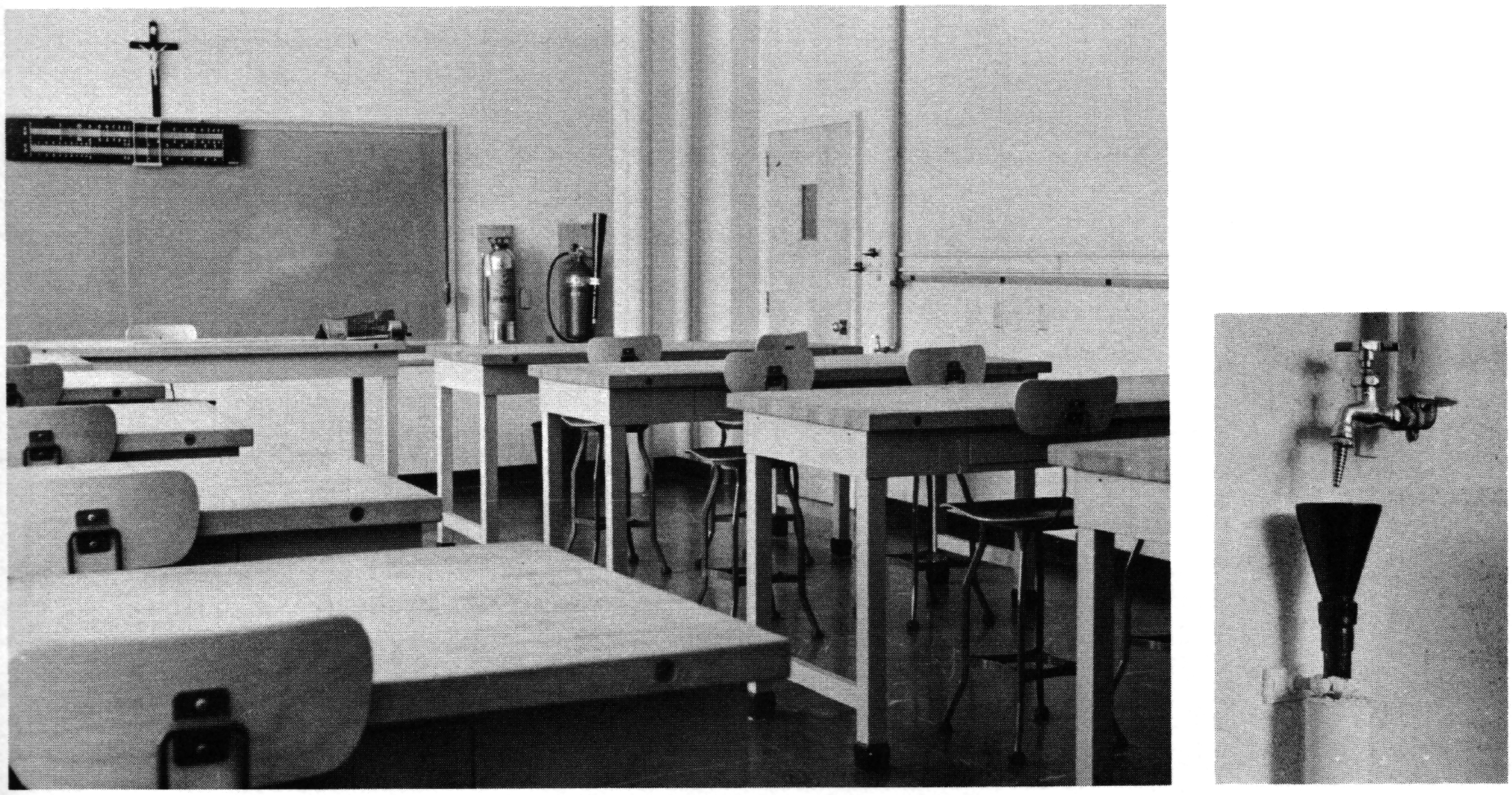


Figure 3. Elementary physics laboratory at the University of Texas. Utilities are distributed by way of a service island.

Figure 4. Elementary physics laboratory at Catholic University of America. Note the fire extinguishers mounted on the front wall. Photograph at right shows funnel on drain pipe which serves as a simple sink.



tories at the University of Pennsylvania (Figure 5). Mechanical and electrical services are provided by service islands of which there are four in each laboratory. Two fixed tables (30 by 60 by 36 inches) are associated with each service island. Since the service island is the same height as the tables a long horizontal working surface is available for those experiments which require it. Each laboratory accommodates 16 students with two working at each table. Incorporated in each service island is a stone sink with cold water, outlets for compressed air and gas, electric outlets for 120-volt 60-cycle ac and the 120-volt dc house generator, and jacks for two pairs of free lines which run to a distribution panel in the laboratory. There are six such elementary laboratories and three apparatus storerooms in the physical science building at the University of Pennsylvania. Every two laboratories have a common storeroom between them and are reserved for the laboratory work associated with certain phases of the elementary course. The plan shown in Figure 5 is for the pair of laboratories used for experiments in electricity. Each of these laboratories has a small side room in which galvanometers are housed. Small side rooms off the two laboratories which are used for mechanics are for balances.

An array of three much larger tables (5 by 12 feet) is used in each of the two freshman laboratories at the University of Kansas (Figure 6), and a similar array is used in the two sophomore laboratories. The tables are fixed in position and accommodate eight students each, four on each side, for a total of 24 students in each room. Instead of using service islands, service outlets are attached directly to the tables. A sink which can be covered is supported in a recess at the center of each table, gas and air outlets are on the top of the table, and electrical service is available at each end of the table from outlets on each side of a box mounted on top of the table (ac, dc and free lines from a distribution panel for each laboratory).

Nine tall service islands (each 1 by 3 by 4 feet) are arranged in a three by three array in each of two large laboratories in the new physics building at the University of Georgia—a modification of Scheme B of Figure 1. Each service island supplies gas and electric service for four tables (each 2½ by 4½ by 3 feet) which are grouped around the island as shown in Figure 7. Electric service consists of ac and dc by way of free lines from a sub-distribution panel located in the corridor—a part of the central power distribution system for the building. Water is

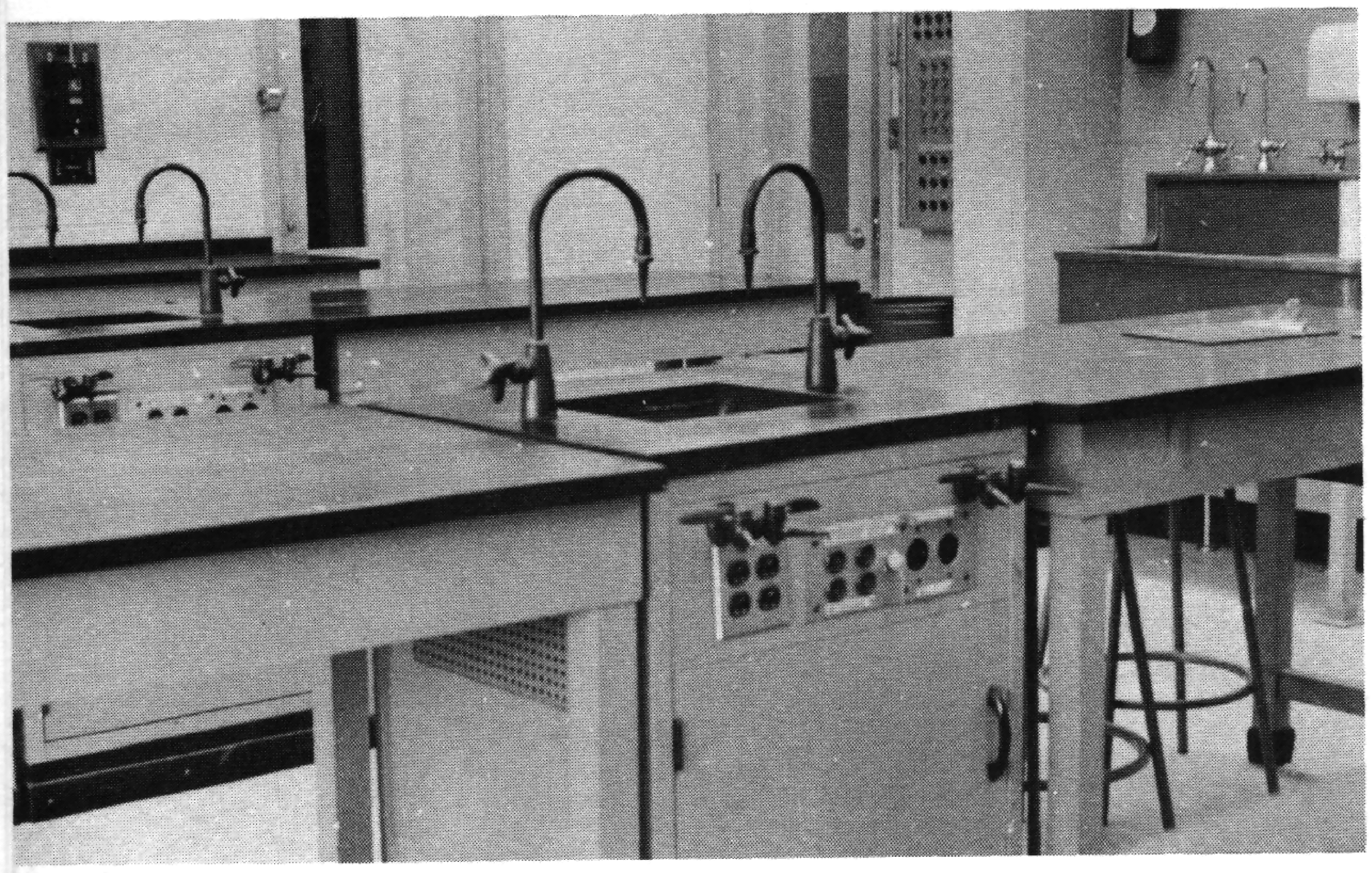


Figure 5. Work tables and service island in elementary physics laboratory at the University of Pennsylvania. Floor plan shows two laboratories and a common storeroom. James R. Edmunds, Jr., Architect, Baltimore, Md.

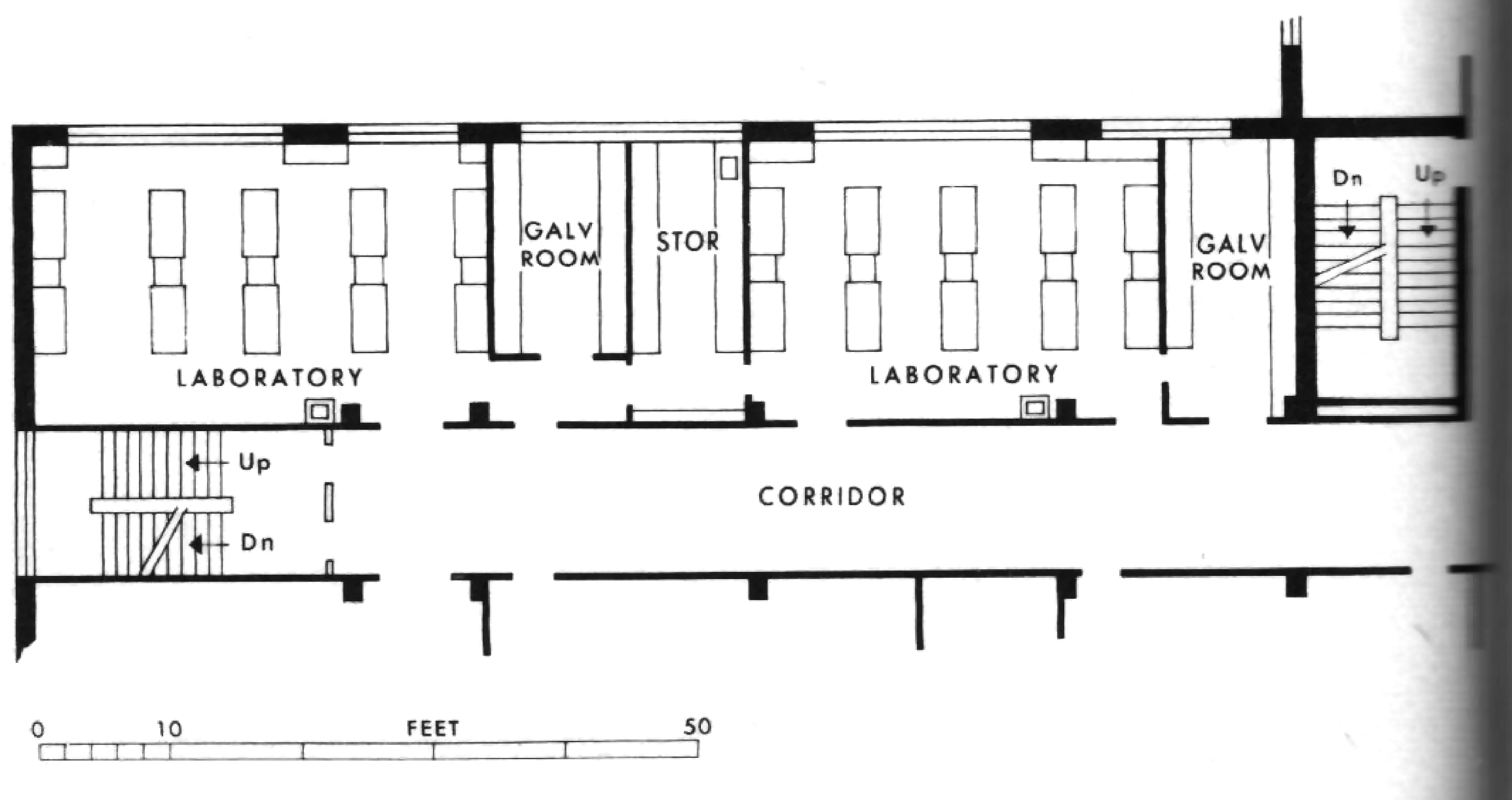
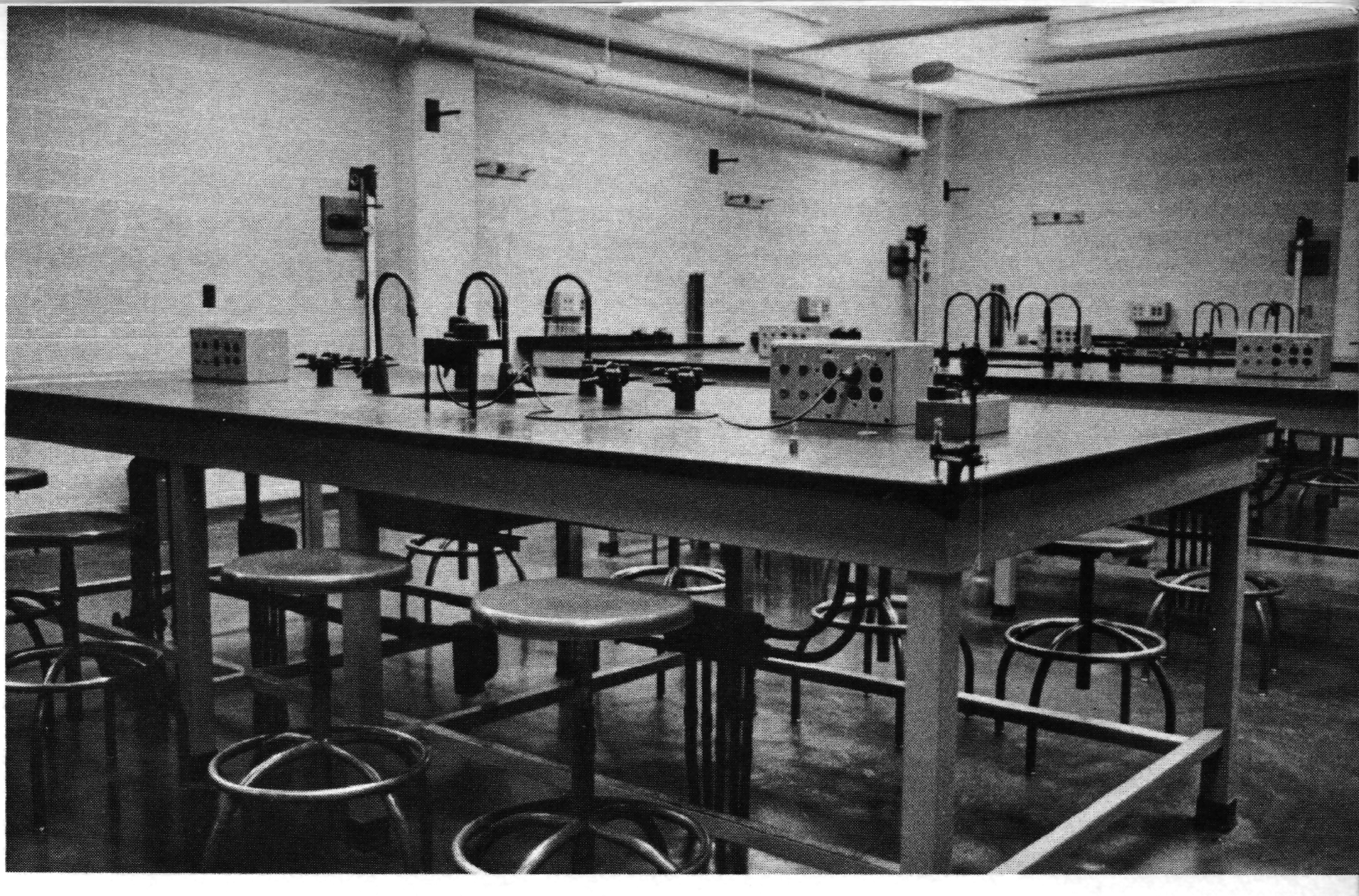


Figure 6. Freshman physics laboratory at the University of Kansas. (See Chapter 4, Figure 23.) Service outlets are attached directly to tables. Floor plan below shows two laboratories and an apparatus room.



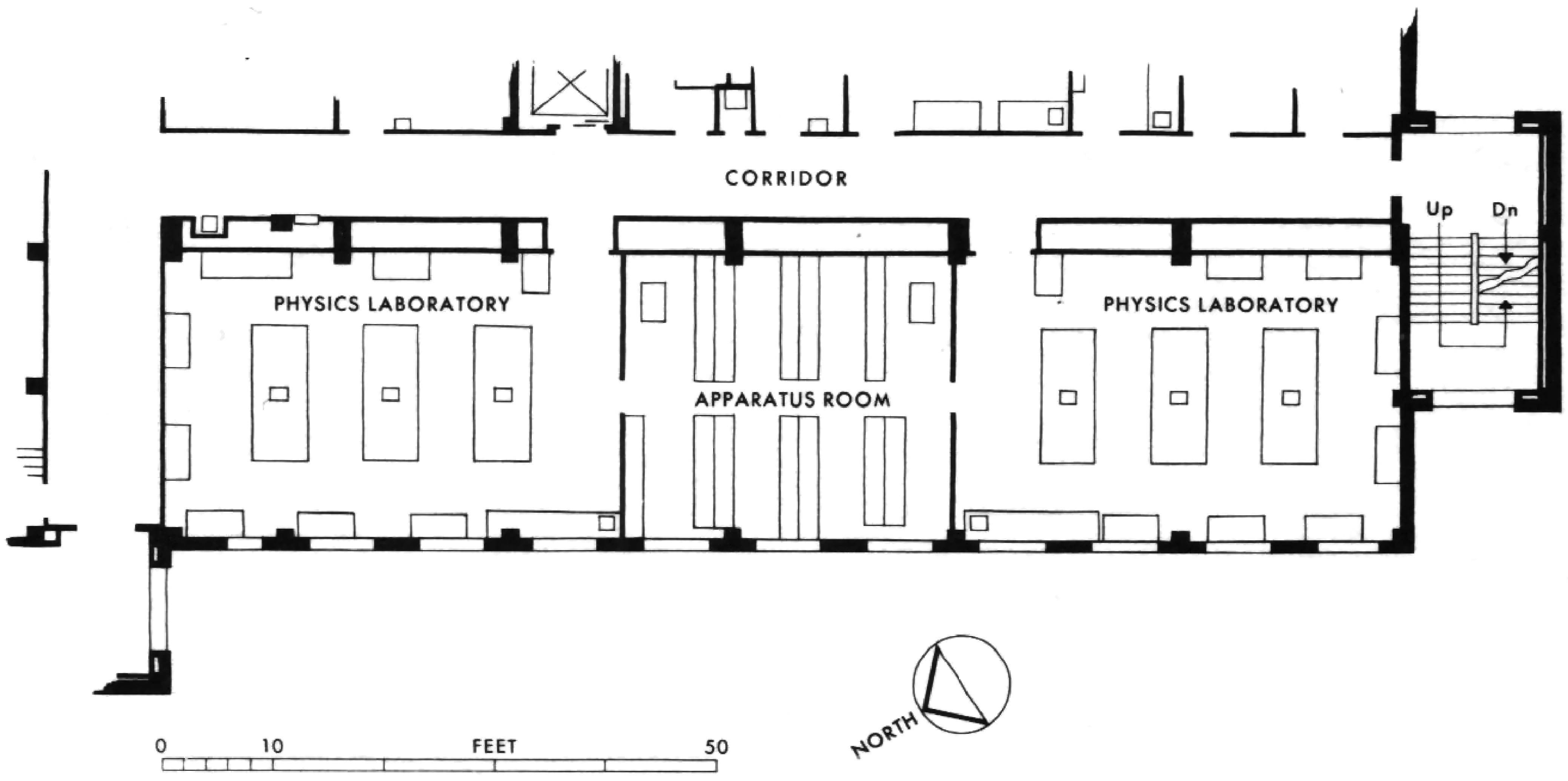
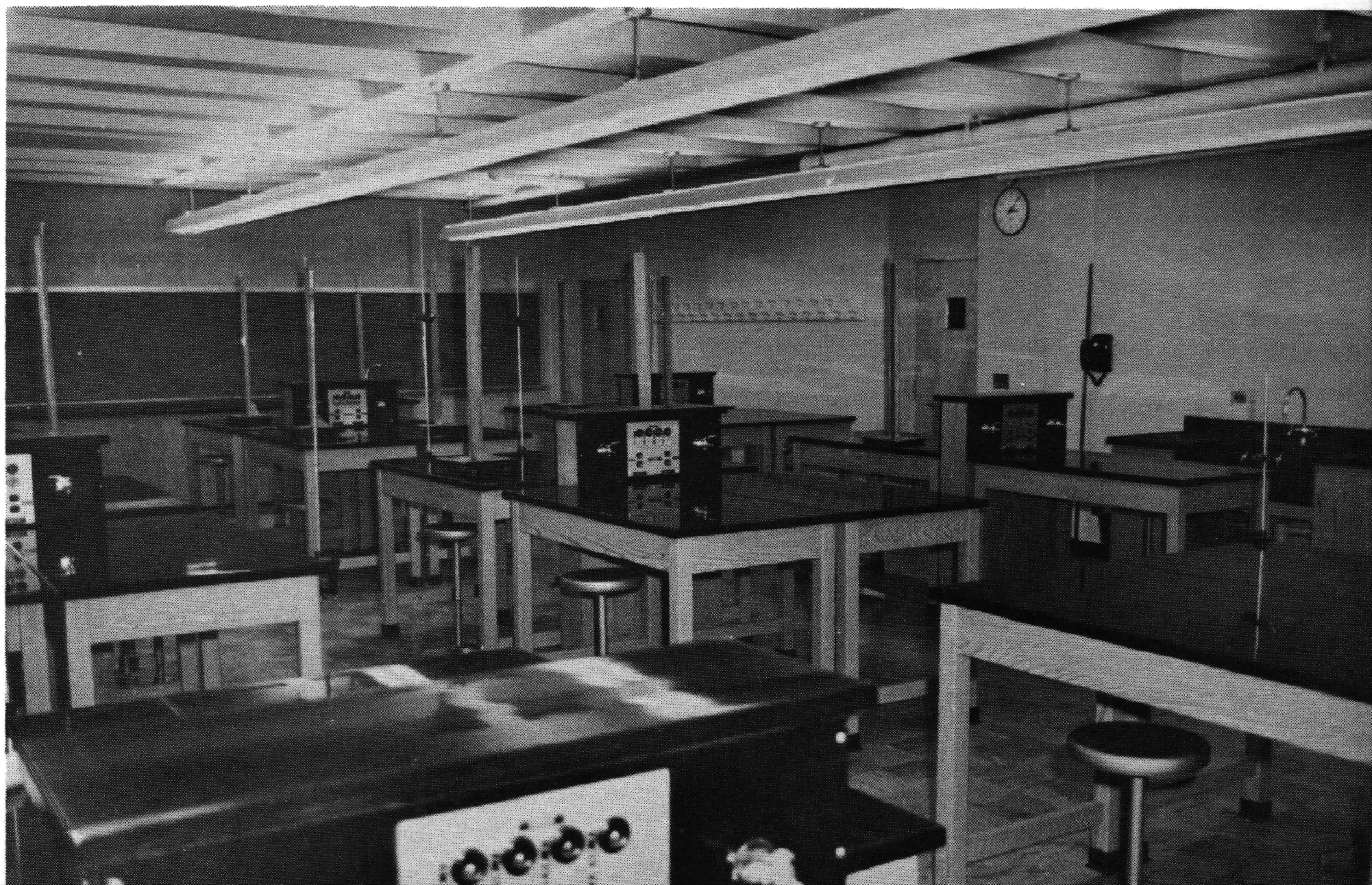

CORRIDOR
Up
Dn
PHYSICS LABORATORY
APPARATUS ROOM
PHYSICS LABORATORY
0
10
FEET
50
NORTH

Figure 7. Large elementary physics laboratory at the University of Georgia. Each tall service island provides utilities for four tables.



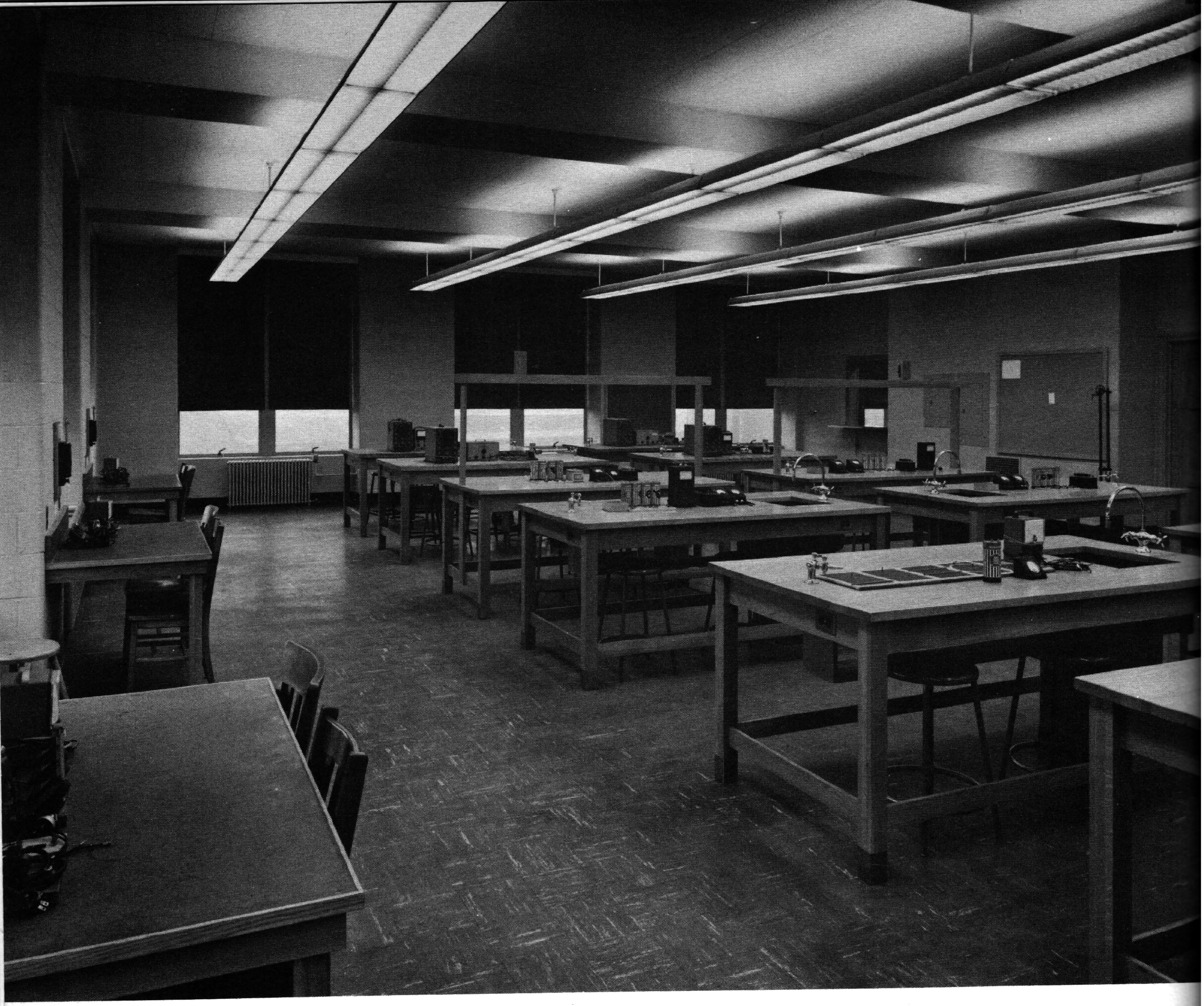


Figure 8. An array of 16 tables in one of the elementary physics laboratories at Northeastern University. Note wooden frames for supporting apparatus on some of the tables.

available at a general purpose sink at one side of the laboratory as well as at a sink in a long table (12 feet) which is installed at the front of the room and equipped for occasional demonstration experiments. Each of the large laboratories accommodates two sections of 16 students each. Five other smaller laboratories are designed to accommodate one section each.

An array of 16 tables (each 3½ by 7 feet by 35 inches) in two rows accommodates 32 students in each of two laboratories in the new physics facilities at Northeastern University (Figure 8). Four of the tables are supplied with a sink and running water (with a faucet for mixing hot and cold water), four have a wooden overhead frame for supporting apparatus and the remaining eight tables have neither of these facilities. This provision of facilities conforms with the normal operation of the laboratory whereby four different experiments are usually under way at one time. Stopcocks for gas are located at one end of each table. Convenience ac outlets and outlets for 115-volt dc (from a local commercial source) are mounted beneath the table top. Portable batteries and rectifiers are used for low dc voltages.

A narrow service island (6 by 1 by 4 feet) provides the mechanical and electrical services for six tables (2 by 6 by 2½ feet) and a second service island serves three tables, in each of the two elementary physics laboratories in the physical science building at Kansas State Teachers College (Figure 9), a pattern similar to that of Scheme C of Figure 1. Three cup sinks with cold water and stopcocks for gas are installed in the top of each service island and electrical outlets (ac and a pair of free lines to the central distribution board) are mounted in panels on the sides of the island adjacent to each station. Laboratory apparatus is housed in a storeroom between the two laboratories.

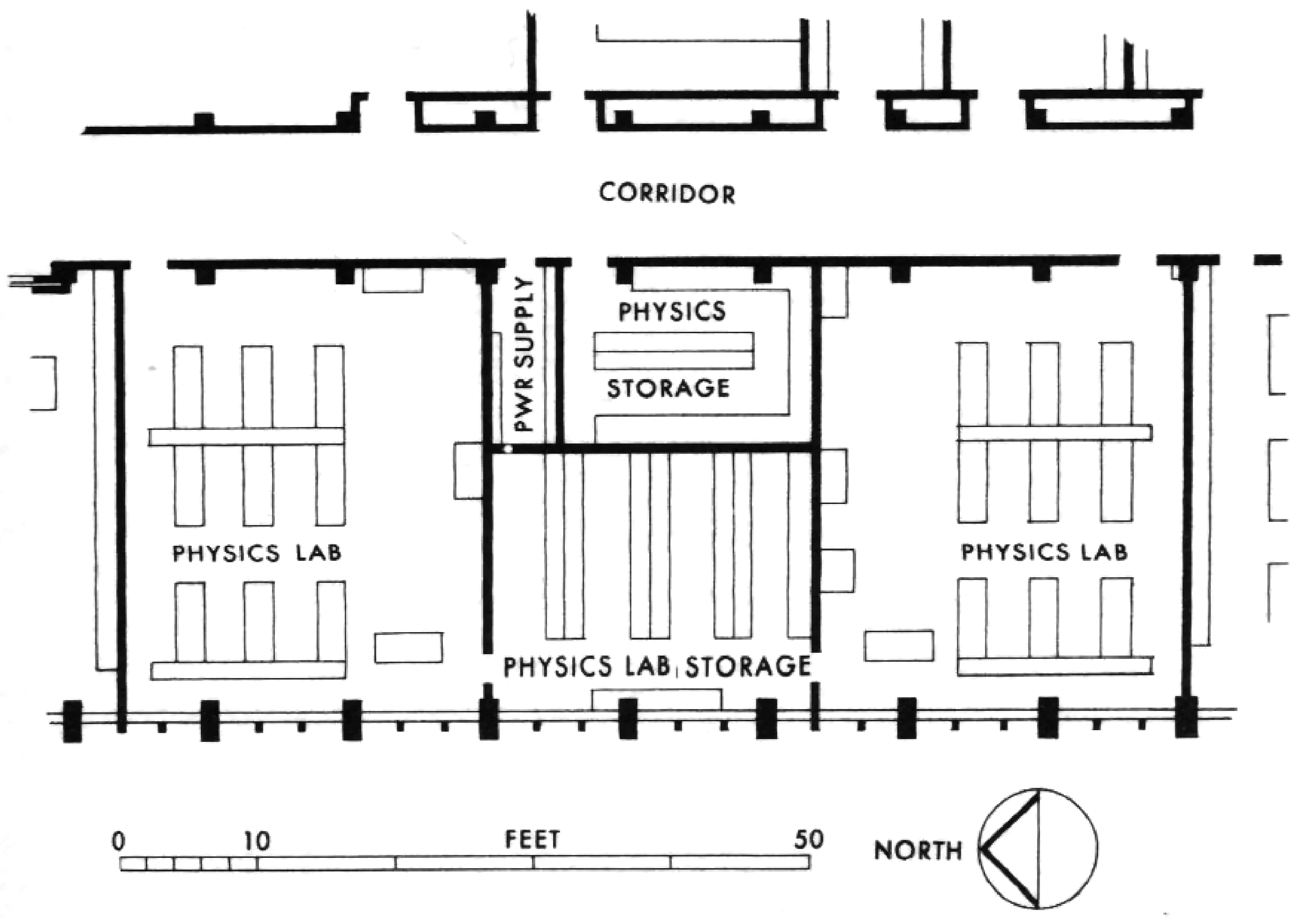
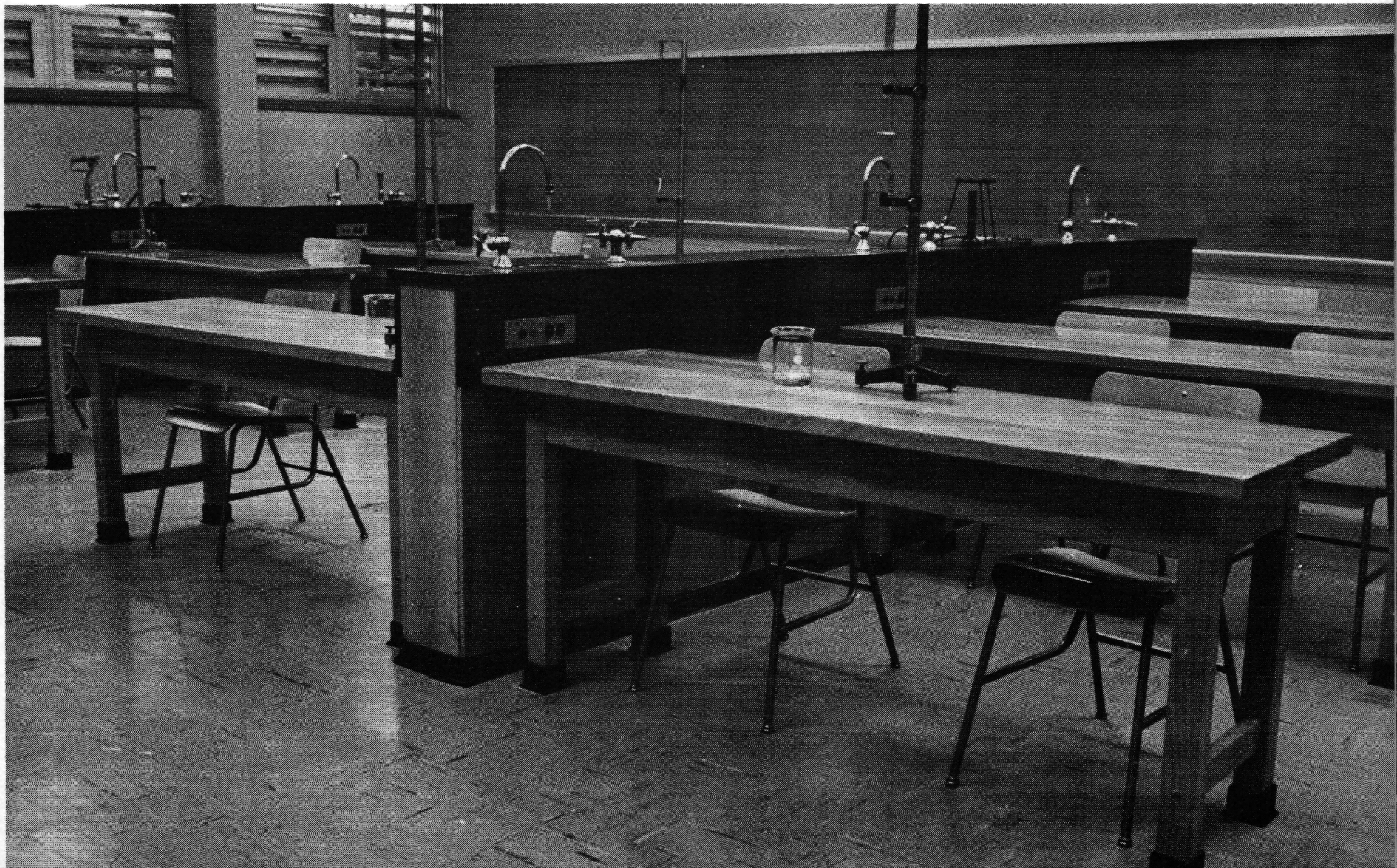


Figure 9. General physics laboratory at Kansas State Teachers College. (See Chapter 4, Figure 22.) Floor plan shows relationship between laboratories and storeroom.



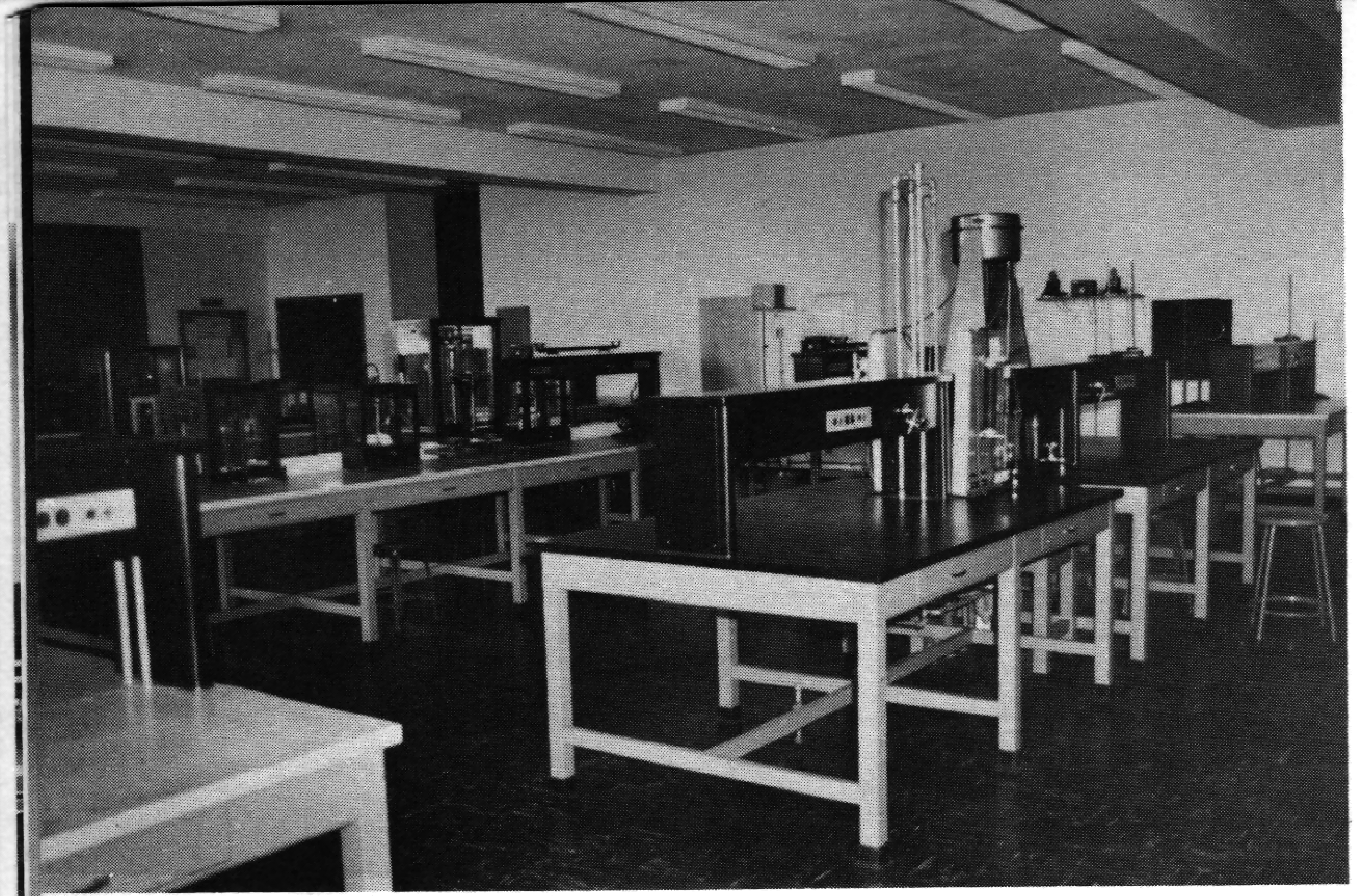
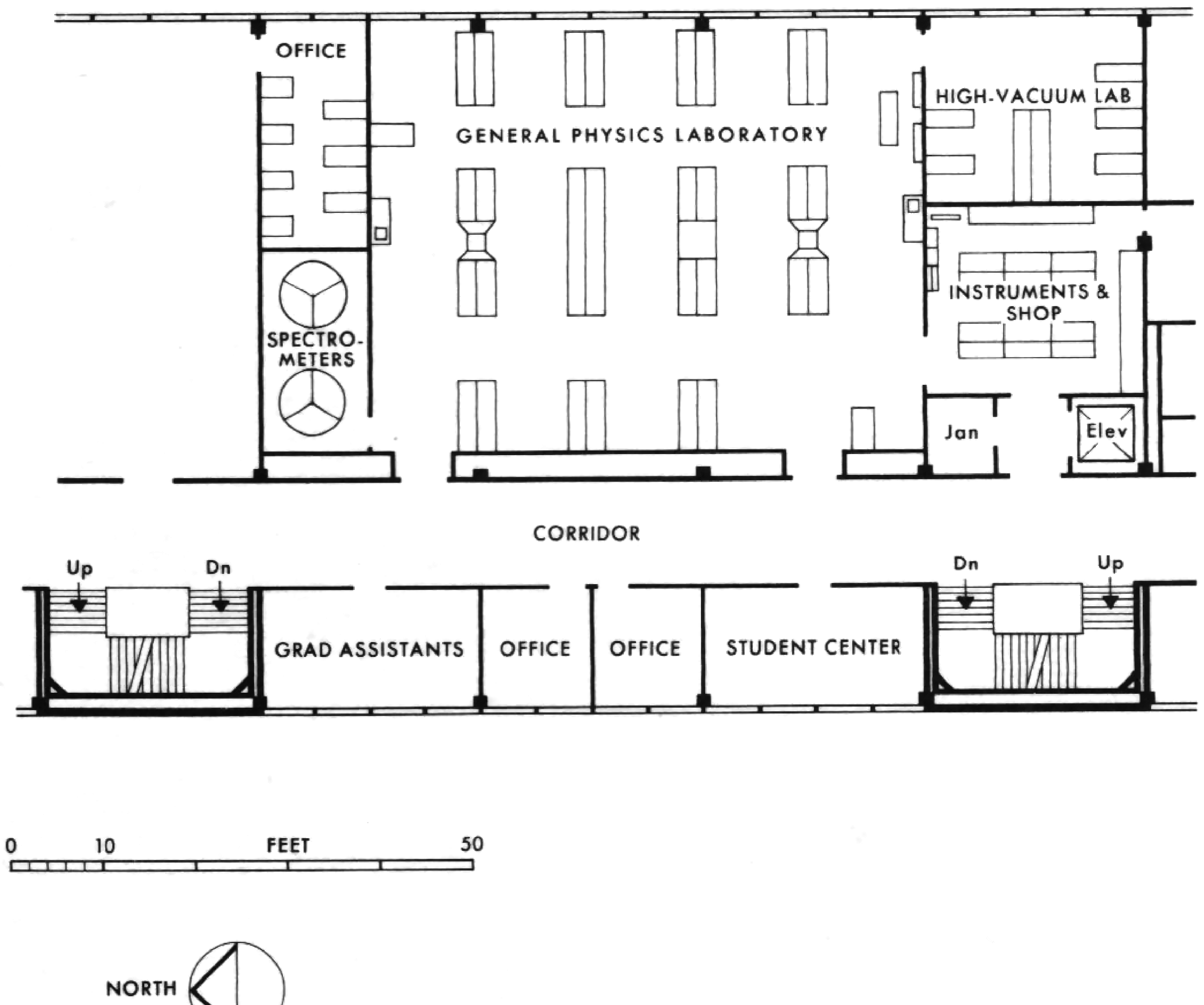
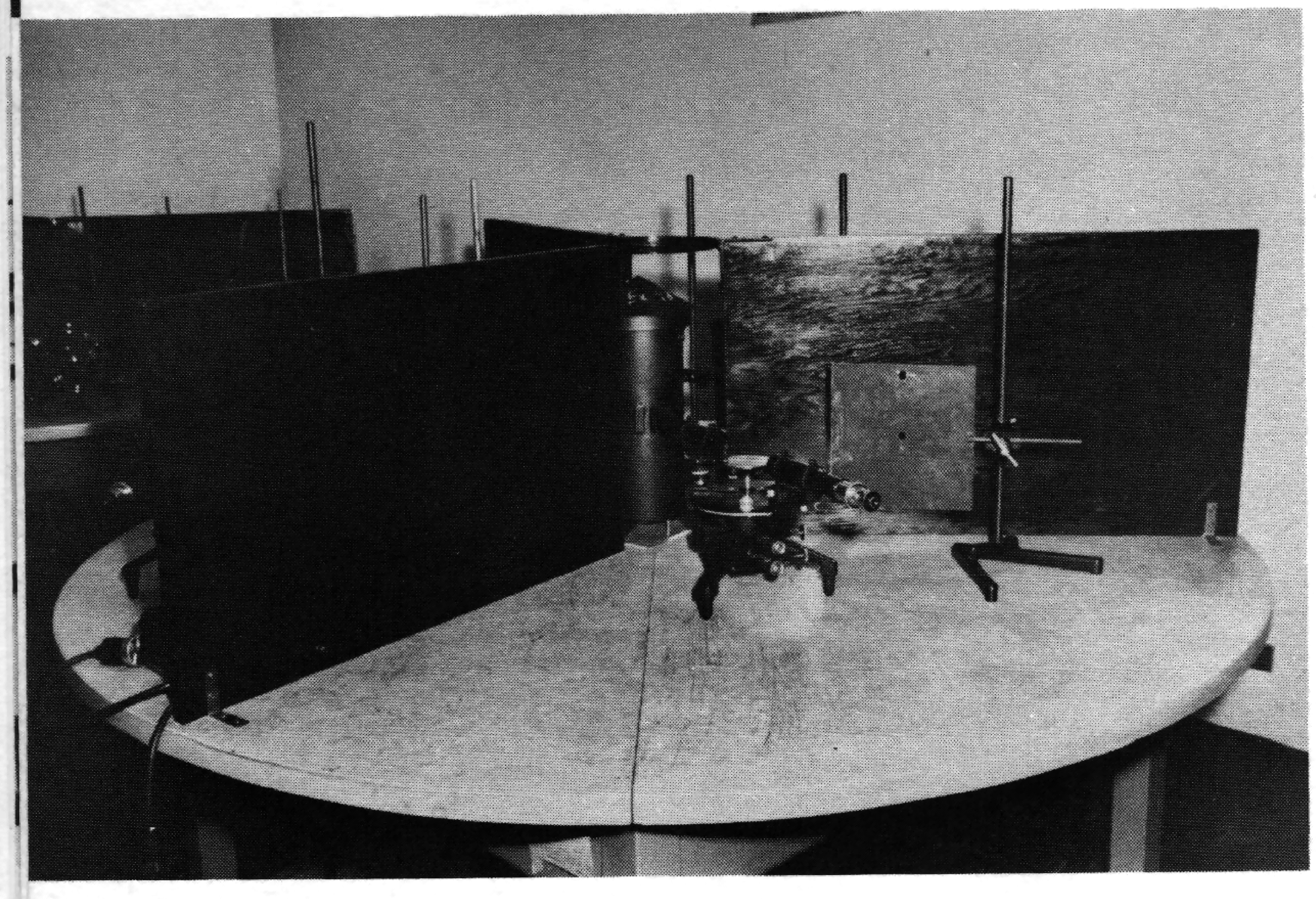


Figure 10. General physics laboratory at Illinois Institute of Technology. (See Chapter 4, Figure 21.) Note framework and shelf above each table for supporting apparatus and mounting utility outlets.



The large elementary physics laboratory (46 by 60 feet) in the new Physics-Electrical Engineering Building at the Illinois Institute of Technology has work tables placed along the side walls as well as in the center of the room (Figure 10). Water is provided in sinks associated with two of the central sets of tables and at two other general purpose sinks located one at each end of the room. Gas and ac and dc outlets are provided at each station in a metal frame which runs the length of each table and supports a shelf about 20 inches off the table. Low voltage dc is supplied by free lines which run to a distribution board and battery installation in the adjacent storeroom. A significant feature to note in connection with this laboratory is the generous spacing between tables. Note also the two side rooms, one for experiments in acoustics and the other for optics.

The elementary laboratory at Pomona College is divided into open-ended cubicles by means of partitions (Figure 11). The partitions not only minimize "cross-talk" between students but also provide additional wall space for supporting apparatus. Mechanical and electrical services reach the cubicles by way of a service island which runs the length of the outer wall of the laboratory. In Figure 11 (e) a section of the lower panel of the service island is shown removed to reveal how water, air, and gas are brought up to the horizontal feeder lines and to show how these and the electrical services are brought to the upper panel and to the cup sink. Note the cutoff valves for each of the mechanical services. In addition to convenience ac outlets, each station is provided 120-volt dc from the house generator, a ground connection, and jacks for two pairs of free lines from a subdistribution panel connected to the central distribution system. (The central distribution system at Pomona is described in Chapter 3.)



Spectrometer table in side room of laboratory. Three spectrometers can use the same light source.

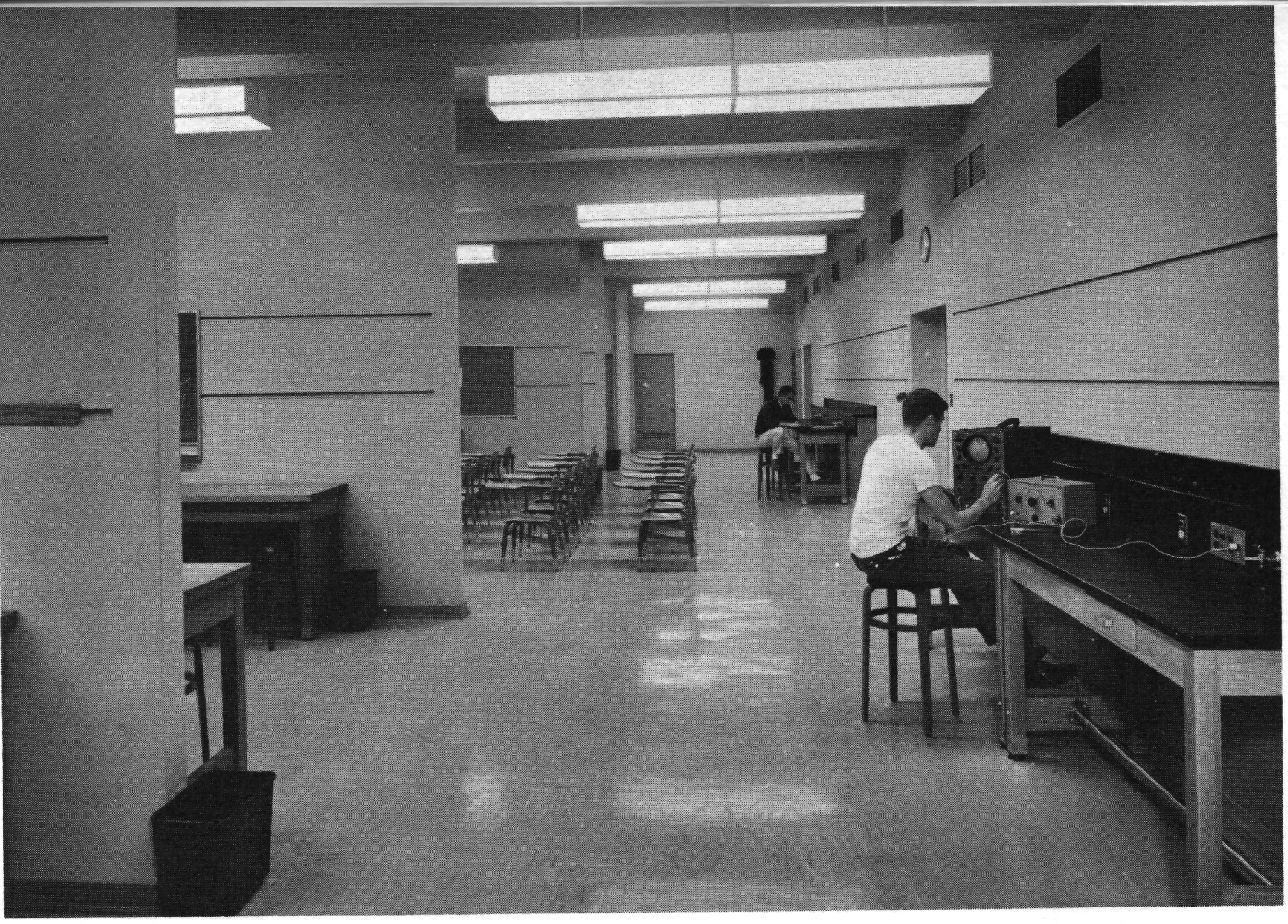
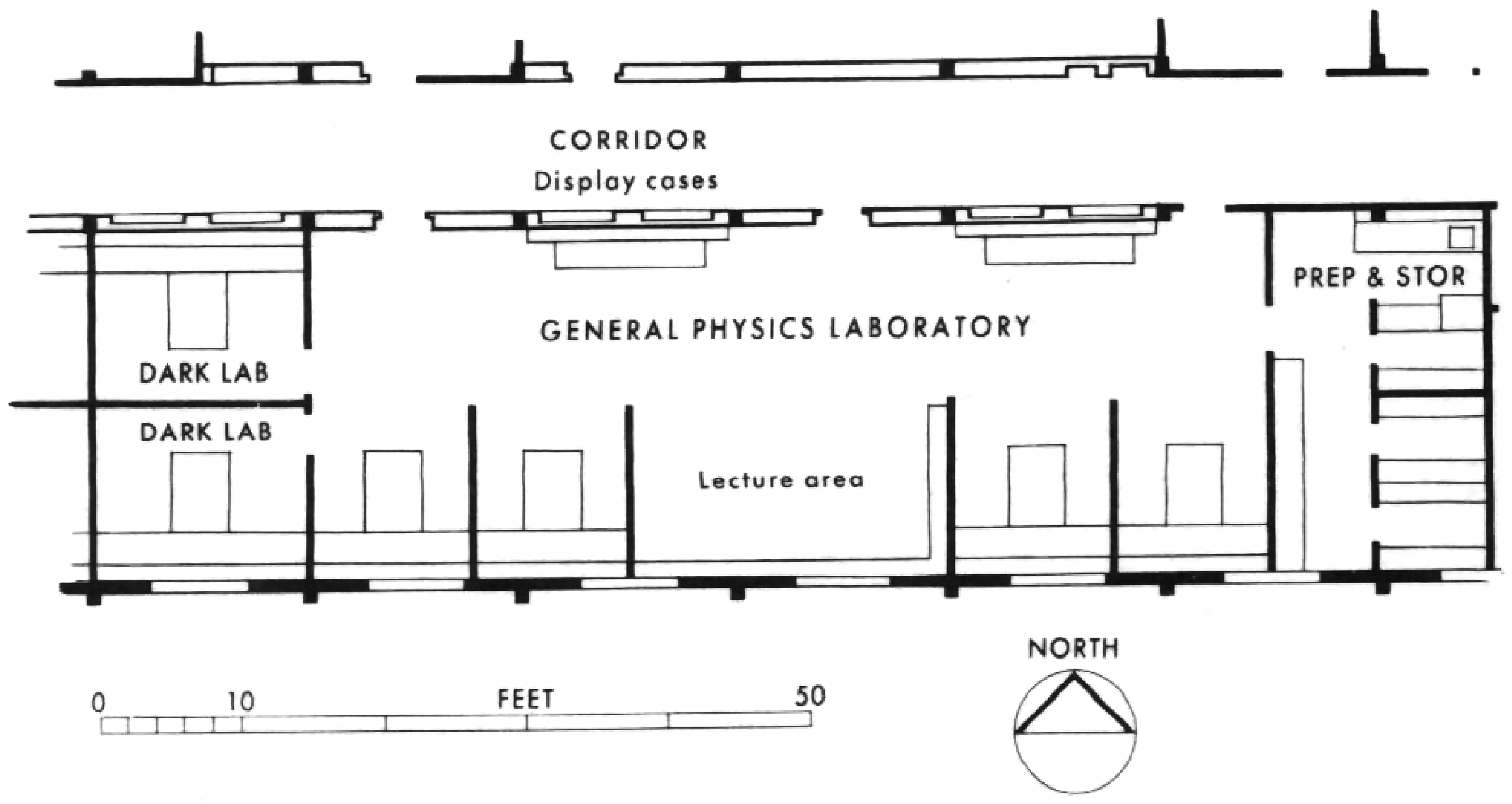
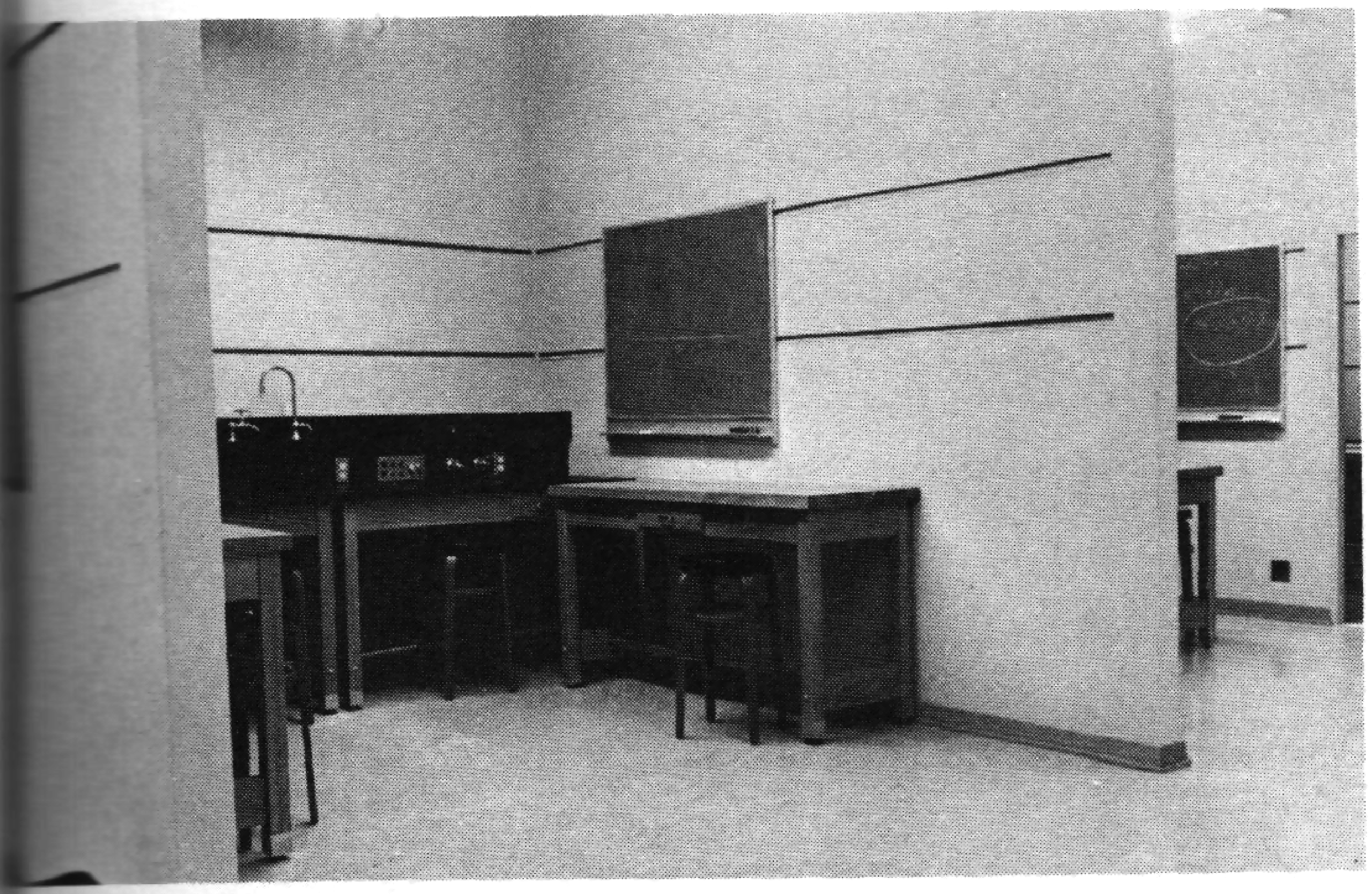
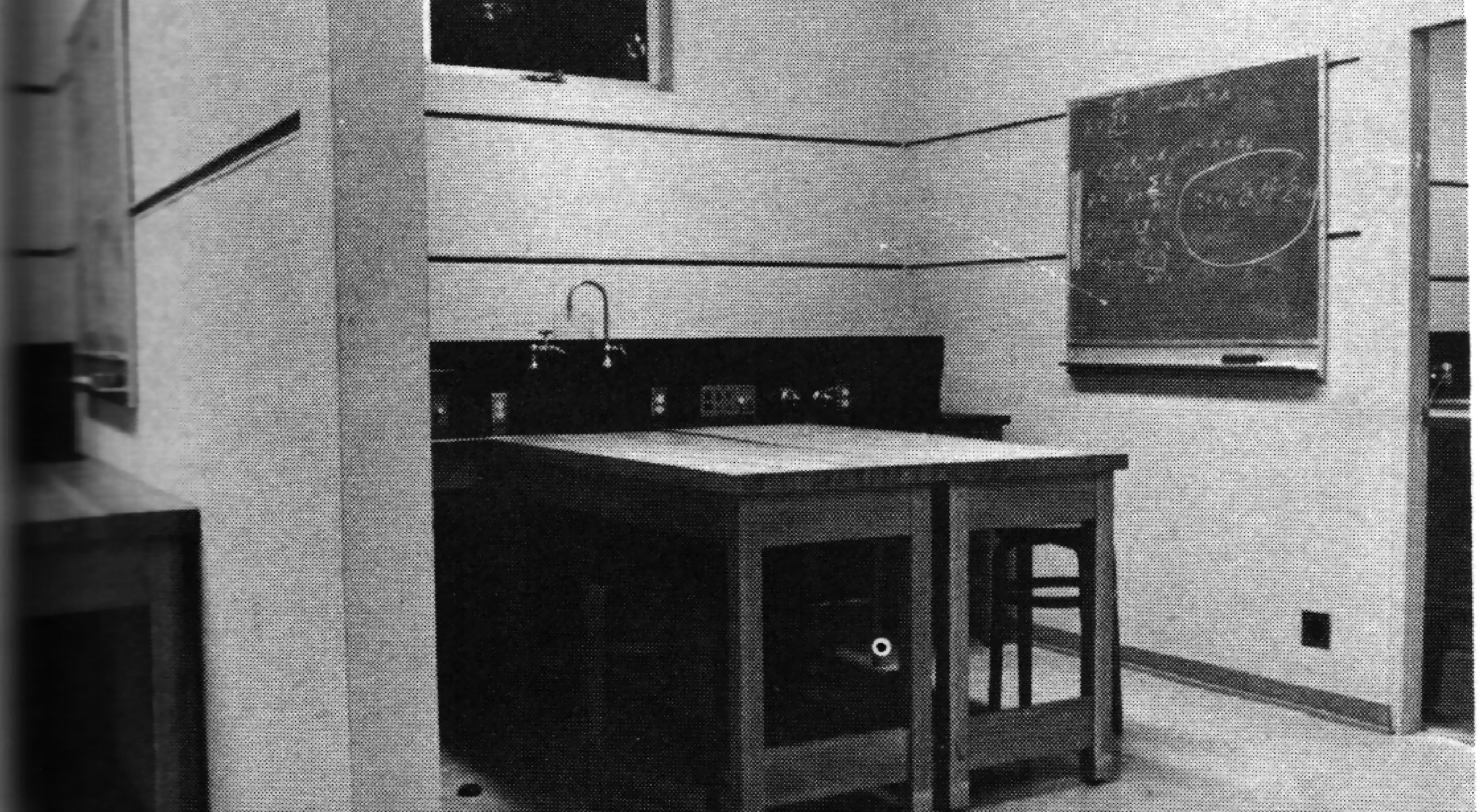


Figure 11. Elementary physics laboratory at Pomona College (Chapter 4, Figure 11). Note open-ended cubicles and wall benches.

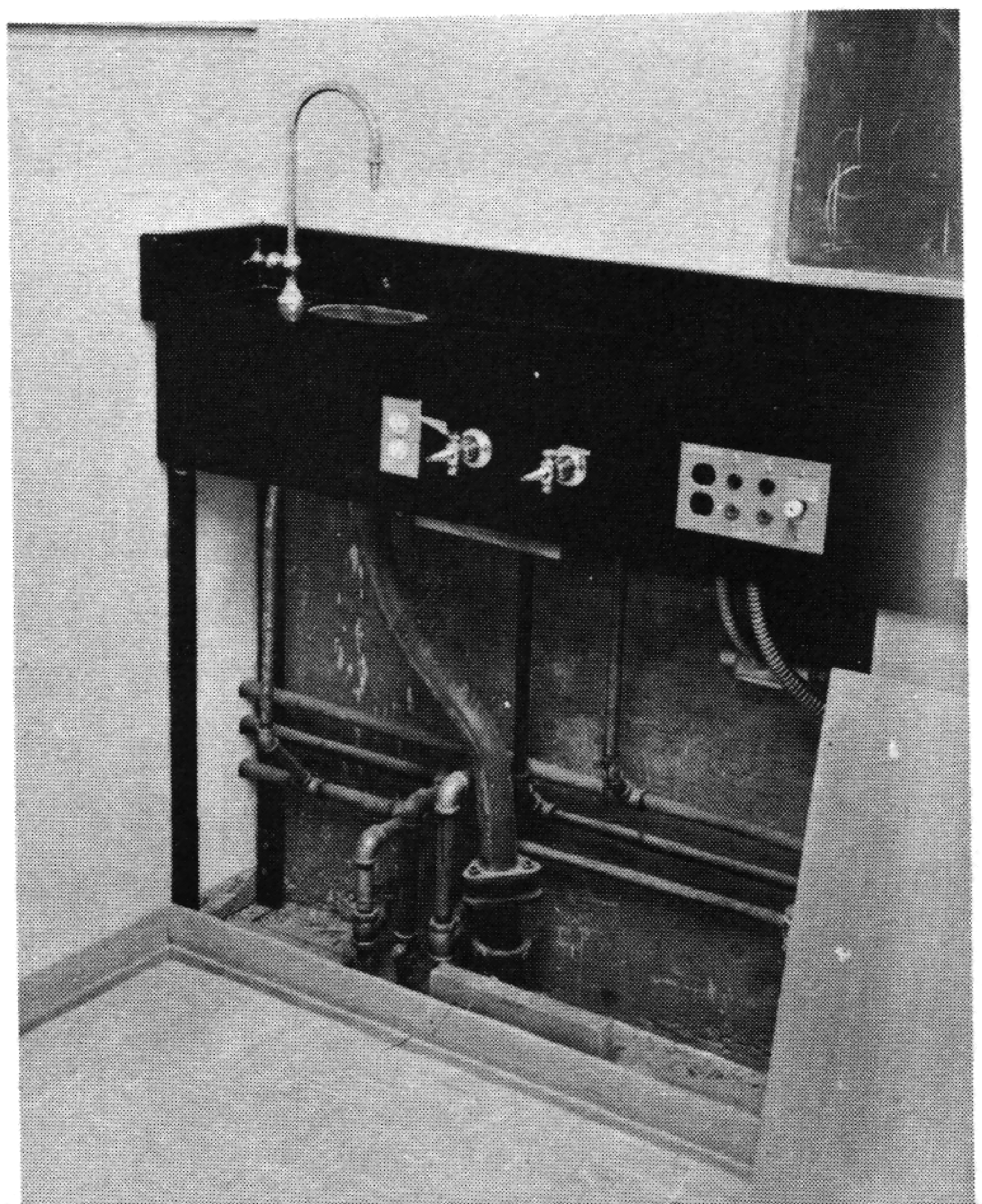

CORRIDOR
Display cases
PREP & STOR
GENERAL PHYSICS LABORATORY
DARK LAB
DARK LAB
Lecture area
NORTH
0
10
FEET
50



Two arrangements of movable tables in cubicles.



Service island with front panel removed. Note shut-off valves for water and gas.



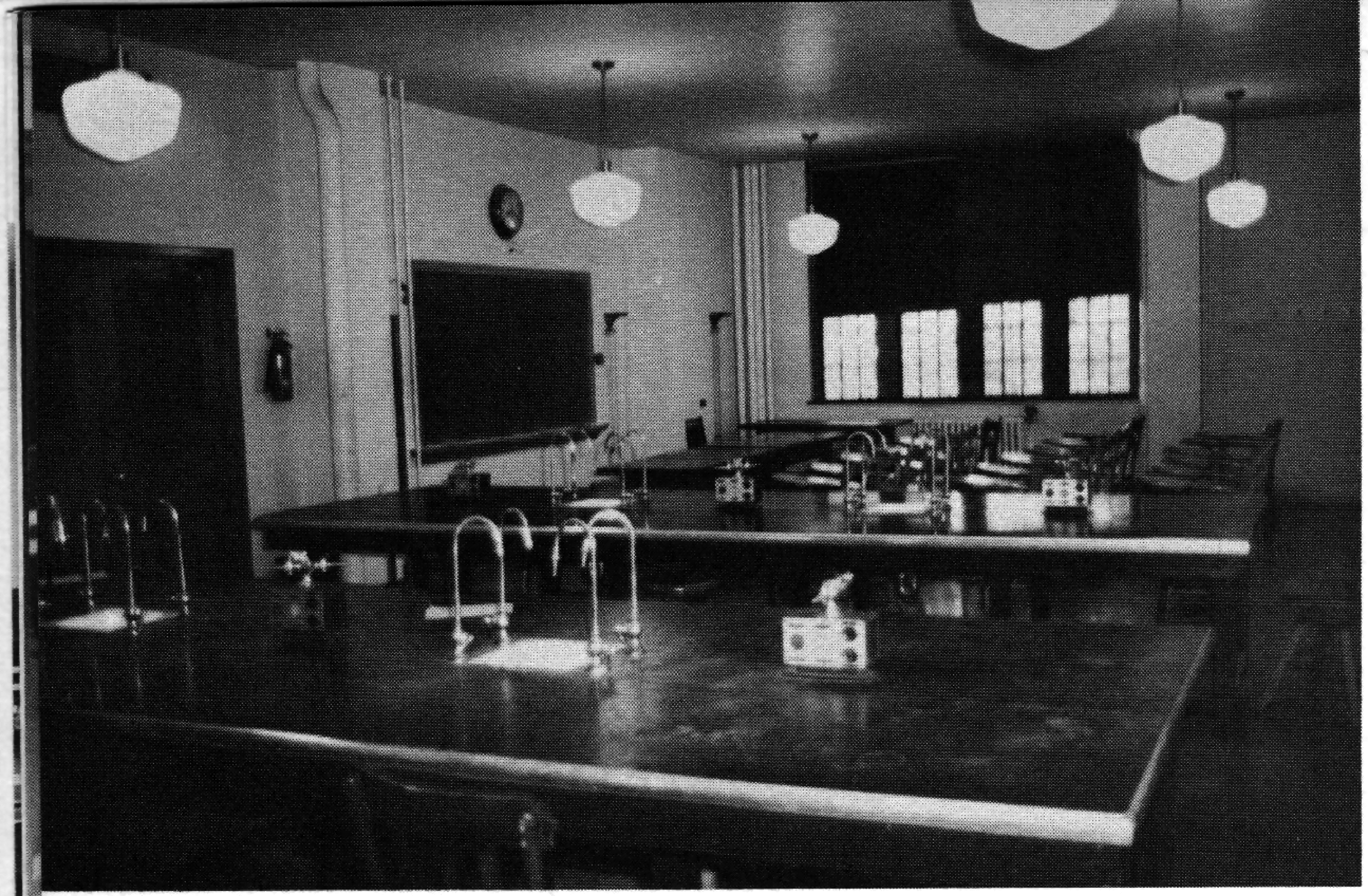
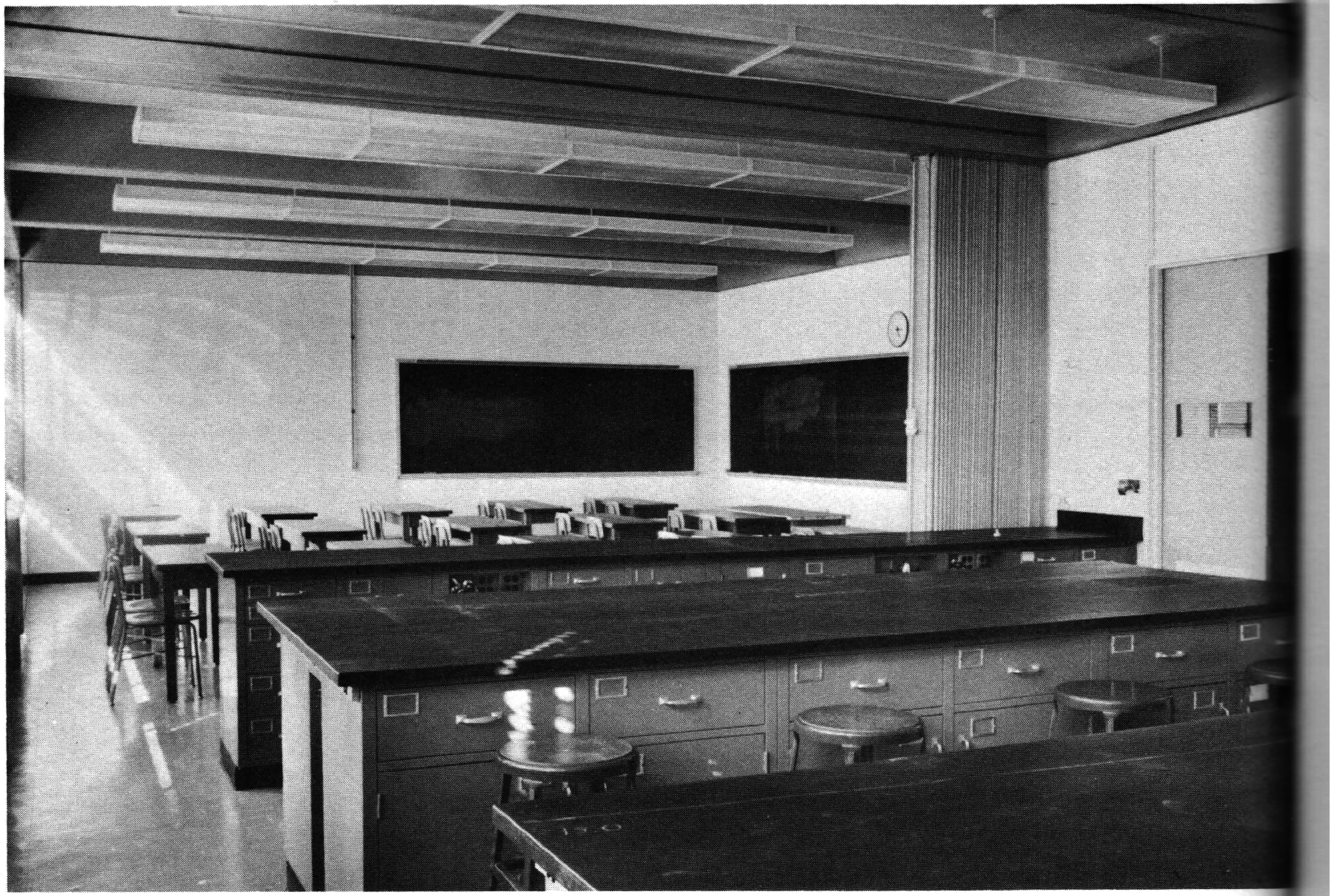


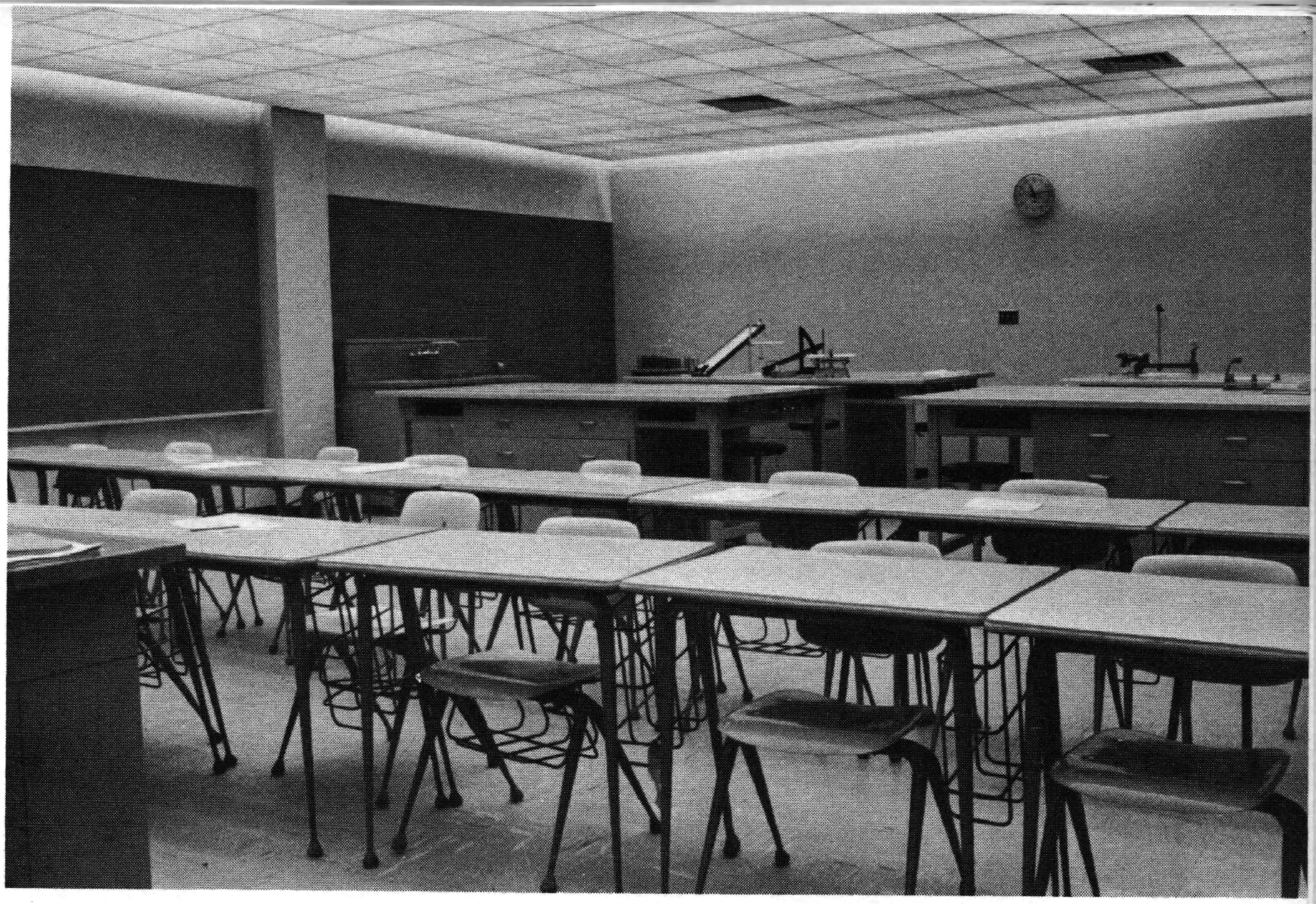
Figure 12. Space at one end of elementary physics laboratory at the University of Indiana is furnished with tablet-arm chairs for discussions and quizzes.

Figure 13. Elementary physics laboratory at Swarthmore College. Folding partition is used to separate classroom area from laboratory.



Combination Laboratory and Classroom

At some institutions a small area is set aside in an elementary laboratory for chairs with tablet arms as is done in one of the laboratories at the University of Indiana (Figure 12). Here a laboratory section or small group of students can be assembled for preliminary instructions or for a quiz. A similar procedure is used in the new physics laboratories at Swarthmore where, instead of tablet arm chairs, small tables and chairs are provided in the instructional area as shown in Figure 13. This area is used by students for making calculations after data has been taken, as well as for receiving pre-



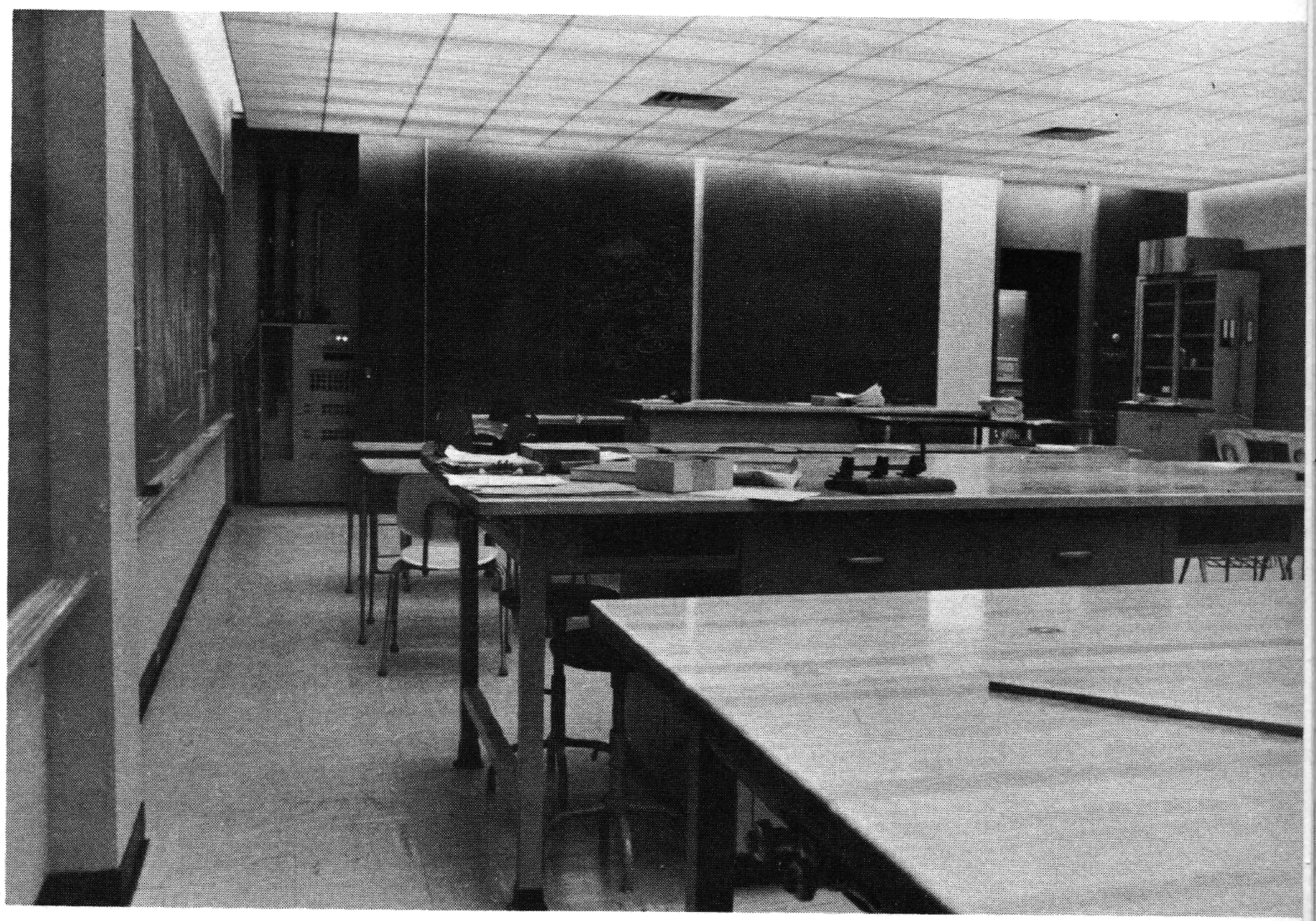
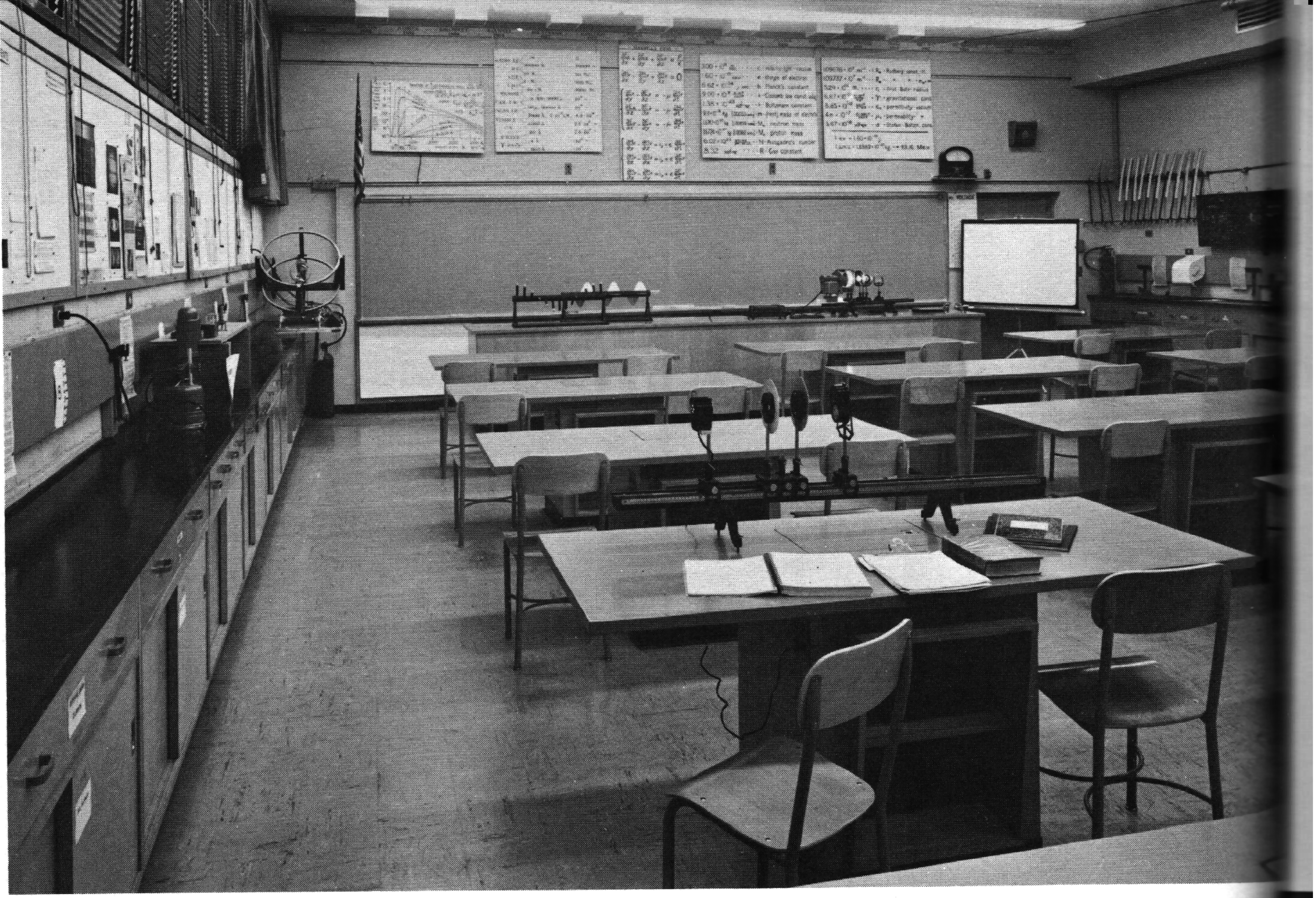


Figure 14. Two views of the combination laboratory and classroom used for elementary physics at the Air Force Academy. Note large writing surface at student desks (above) and sliding chalkboards (below).

liminary instructions and taking quizzes. Other classes also use this area when the laboratory is not in use. A folding partition can be drawn between the two areas so that, if necessary, the laboratory can be set up when such classes are in session. Note that the space beneath laboratory tables, is completely filled with cabinets for storing apparatus. At no place other than Swarthmore did we see such an extensive installation of cabinets.

At institutions where all physics classes are kept small it may be desirable to hold both classroom and laboratory activity in the same room. For example, this is done at the Air Force Academy (Figure 14) and at El



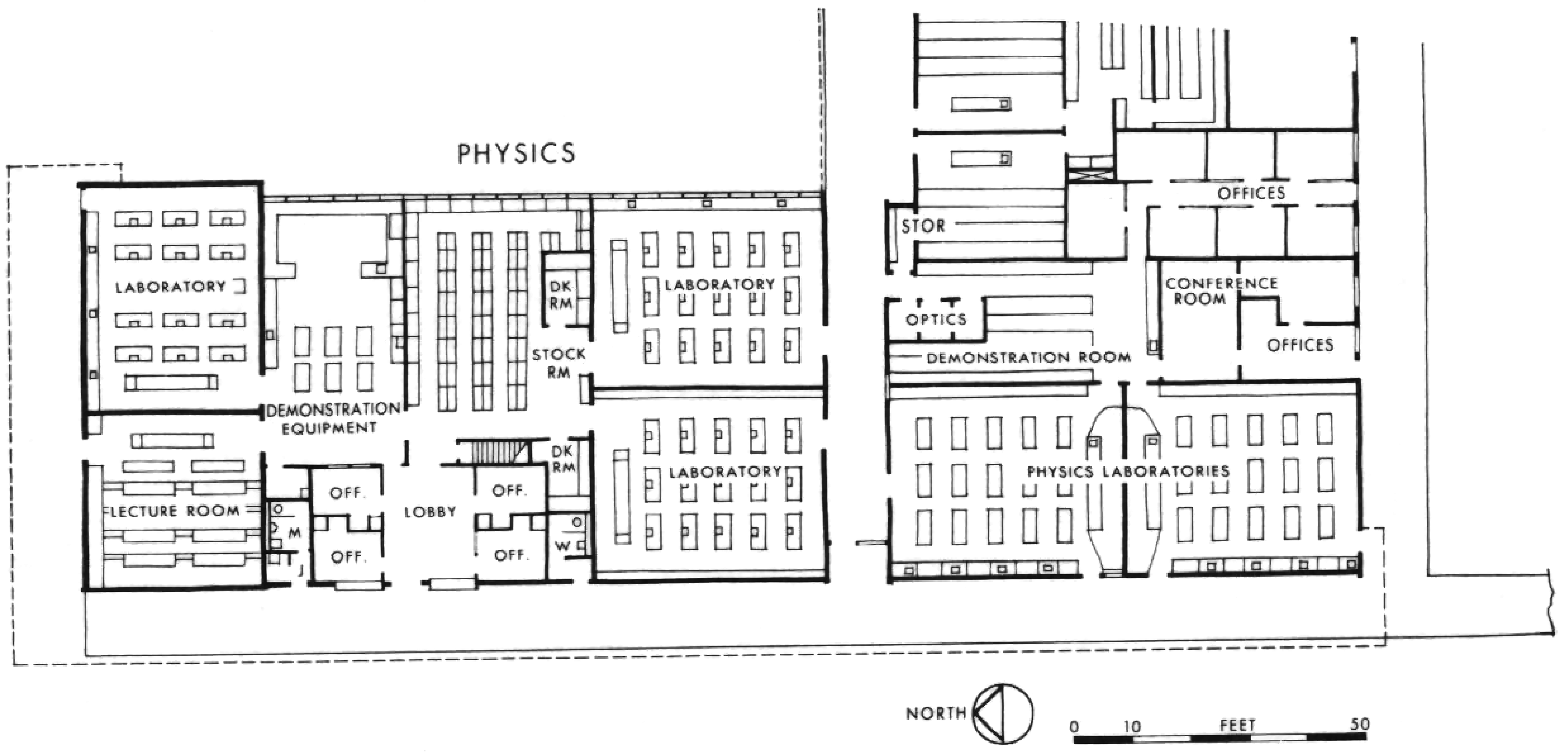

PHYSICS
LABORATORY
DEMONSTRATION EQUIPMENT
DK RM
STOCK RM
LABORATORY
DK RM
LABORATORY
LECTURE ROOM
M
J
OFF.
OFF.
LOBBY
OFF.
OFF.
W
STOR
OFFICES
CONFERENCE ROOM
OFFICES
OPTICS
DEMONSTRATION ROOM
PHYSICS LABORATORIES
NORTH
0
10
FEET
50

Figure 15. Combination laboratory and classroom at El Camino College (Chapter 4, Figure 19). Note demonstration table at front, and Unistrut and wood boards on side walls for supporting charts and apparatus.

Camino College (Figure 15); at neither place is a separate lecture room used for any of the regularly scheduled activity of the classes. The back end of each physics room at the Air Force Academy is equipped as a laboratory and the front end as a classroom, with a lecture table which is supplied with the utilities required for demonstrations. Classes are held to a maximum of 14 students. At El Camino College, three rows of five specially designed tables in each row provide laboratory work space for a maximum of 30 students and also serve as desks for class work. A lecture table fitted with the necessary utilities is installed in the front of the room, and benches with cabinets beneath them are installed along each side of the room. Note the good use that is made of the metal channels on the side walls and ceiling and the wooden board above the benches for supporting charts and miscellaneous experimental apparatus.

Storage of Apparatus

The storeroom in which the large amount of apparatus required for the elementary laboratory is stored should be located as convenient to the laboratory as possible to minimize the task of distributing apparatus. Wherever possible the storeroom should be next to the laboratory, with a door between the two rooms so that apparatus can be transferred from one room to the other as directly as possible and without interference from traffic in the corridor. Where there are two elementary laboratory rooms, they are usually served by a common storeroom located between them, as at the University of Kansas (Figure 6).

When an institution has more than two elementary laboratories, a single large storeroom may serve all laboratories; at the University of Florida one storeroom serves nine laboratory rooms such as the laboratory shown in Figure 2. The large storeroom at the University of California at Berkeley, (Figure 16) serves four laboratories. At the University of Pennsylvania six elementary laboratories are served by three storerooms; each storeroom is located between two laboratories (Figure 5). This arrangement is particularly efficient when it is possible to restrict each laboratory to a certain phase of the elementary course work—mechanics in one laboratory, electricity in another, et cetera.

One of the most frequent complaints involves the crowded condition of the apparatus storeroom. The development of new experiments entails new apparatus to be stored. Furthermore, the continued duplication of existing apparatus requires more

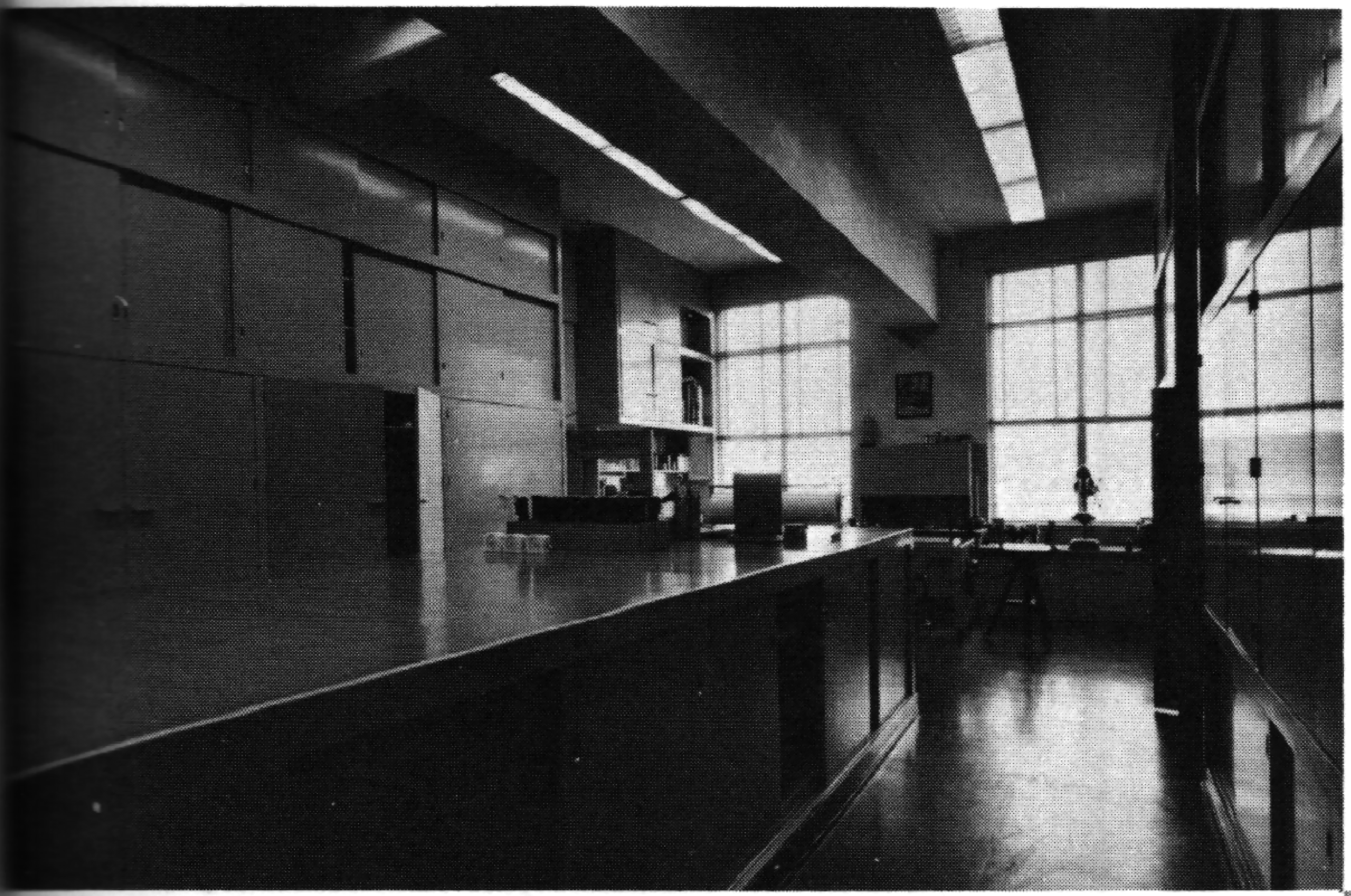


Figure 16. Storeroom facilities for four elementary laboratories at the University of California at Berkeley (Chapter 4, Figure 1). Two views show storage cabinets, work bench and large set-up table. Note cart for transporting laboratory apparatus in photograph below.

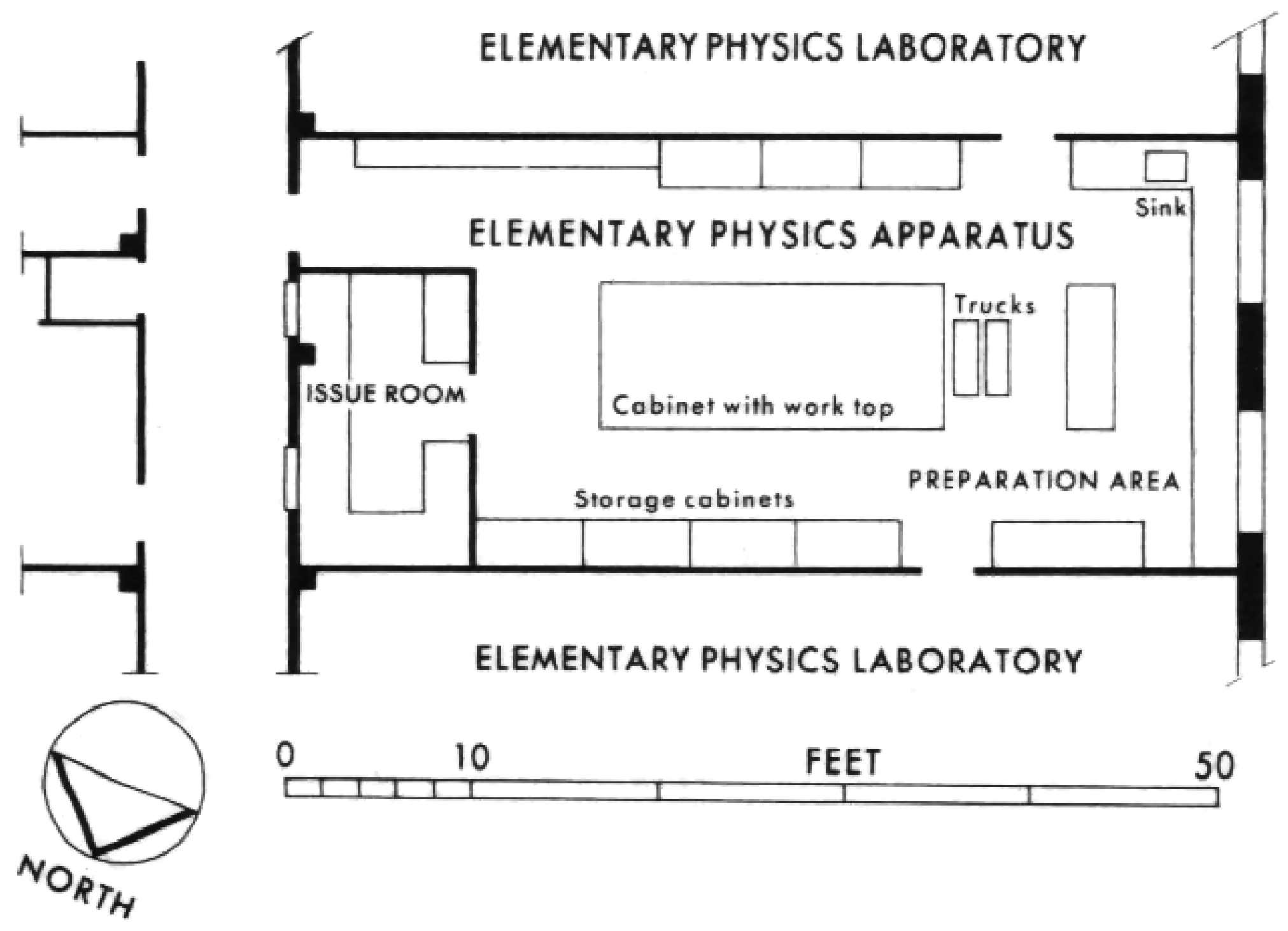


Table III. Storeroom Facilities for the Elementary Laboratory at Selected Institutions

Institution	Size of Storeroom (Feet)	No. of Laboratories Served	Total No. Work Stations In Labs*	Total No. Students Per Semester
California, Univ. of (Berkeley)	50 x 23	4	80	540** Spring, 1960
Florida, Univ. of	20 x 42	9	56	900, Spring, 1960
Kansas, Univ. of	30 x 25 (2 rooms)	4	48	607 (Average, 4 yr.)
Pennsylvania, Univ. of	9 x 21 (3 rooms)	6	48	388 Spring, 1960

* normally, for two students per work station
** 1025 additional students in other laboratory rooms.

space. The size of the storeroom required depends so much on the nature of the laboratory program, including the number of students to be served, that no standard can be suggested. However, some idea of the space needed can be had from Table III which gives the space provided at the schools mentioned together with the total number of student work stations served in each case. A number of persons have suggested that in designing a new laboratory it generally is not safe to plan for less than double the space required for the initial apparatus to be stored.

Storeroom Furniture

Open shelves, cabinets with hinged and sliding doors, chests of drawers, bins, and special racks—all are used for storing laboratory apparatus. Some staffs prefer wooden cabinets; others prefer steel. Because of their convenience, open cabinets are widely preferred for storing apparatus which can easily be dusted. Closed cabinets and chests of drawers of different size and different depth are required for many other items. The staff at one institution where only cabinets and shelves were installed expressed concern over the lack of drawers. The advantage of glazed doors in cabinets is generally agreed upon, though there is no agreement as to preference between sliding and hinged doors. Cabinets should be fairly deep to accommodate as much apparatus as possible and deep enough to take large pieces of apparatus; 22 inches is usually adequate. Shelves should be adjustable in height for greater versatility.

A storeroom should have a work table for setting up apparatus that needs testing, and a work bench with a set of hand tools (as a minimum) for making minor repairs. Gas, air, a sink with cold water, and ac and dc electrical outlets should be provided in this area. The layout of the storeroom at the University of California (Berkeley) is shown in Figure 16. The storeroom serves four laboratories—with a total of 80 work stations.

It is large enough (50 by 23 feet including the sign-out room) so that it is not crowded. A large work table (4 by 20 feet) with cabinets beneath it occupies the center of the room and a work bench extends across one end of the room. Other storeroom layouts are shown in the floor plans in some of the other figures in this chapter.

Carts with wheels are widely used for carrying apparatus back and forth between laboratory and storeroom. At least two of the wheels on such a cart should swivel, and they should be at least 5 inches in diameter and rubber-tired so that the cart will roll freely with a minimum of jarring of apparatus. The carts used at the University of California at Berkeley are designed to simplify the transfer of equipment on and off the carts. They are similar in construction to the carts used in the lecture demonstration storeroom at Berkeley (See Figure 32b in Chapter 5). The upper shelf of the cart is the same height as the laboratory tables and as the first shelf above the base cabinets in the storeroom. Heavy pieces of equipment are therefore normally stored on these shelves.

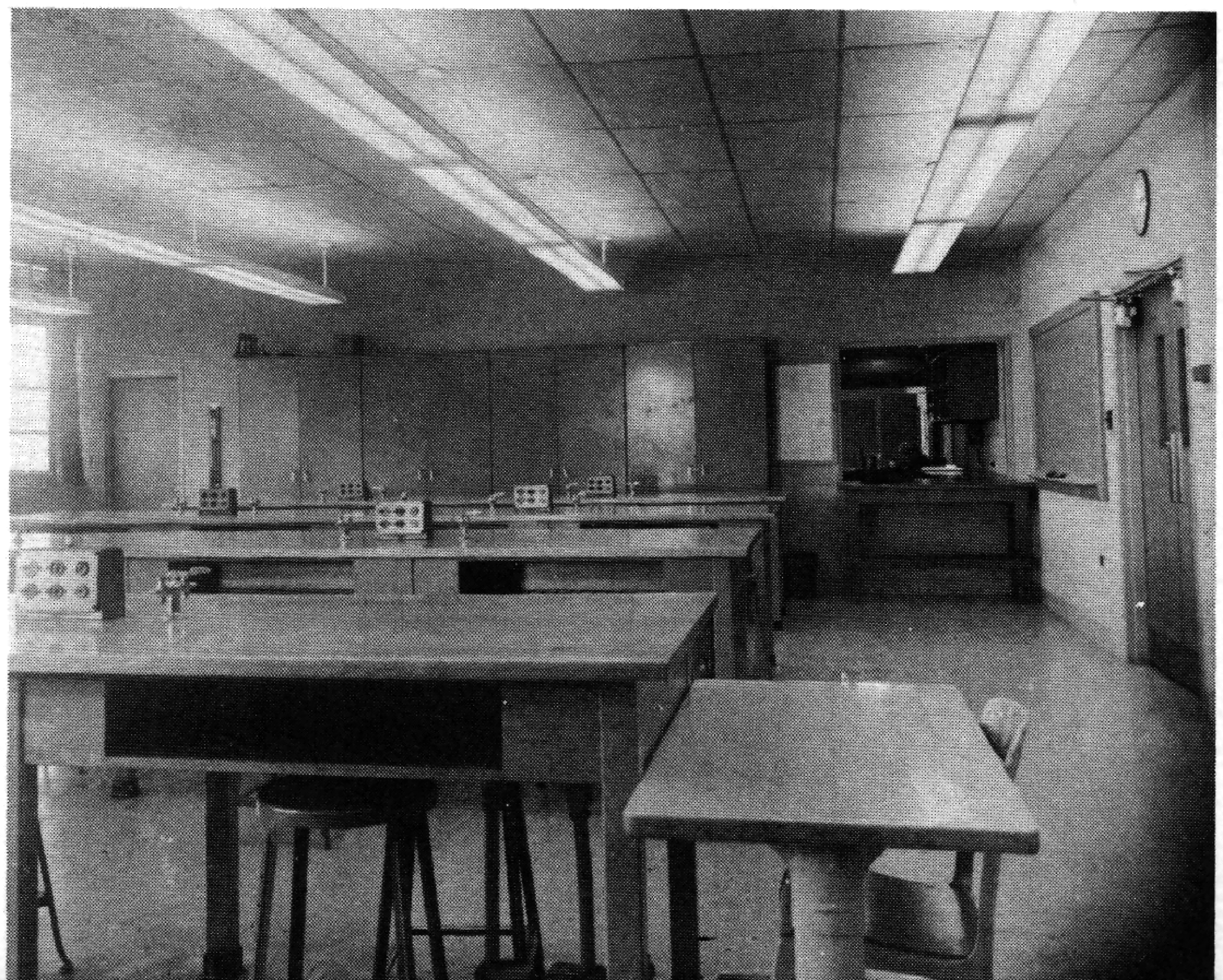
The "Roto Lab" developed at the University of Illinois Undergraduate Division in Chicago uses the "lazy susan" principle to provide temporary storage for apparatus at each work station. It is described in a subsequent paragraph (see Figure 24).

Distribution of Apparatus

Since a different set of apparatus is required for almost every experiment in elementary physics, the distribution of apparatus presents a major problem in a physics laboratory. The solution adopted at different institutions requires varying degrees of self-service on the part of the student. At one extreme, all apparatus is distributed by the staff; the student finds everything he needs for a given experiment already placed at his station at the beginning of the laboratory period. At the other extreme, the student must check out the apparatus required from a storeroom. At most laboratories major items of equipment are distributed by the staff prior to the laboratory period and the student calls at the storeroom only for supplementary items; he may need a stopwatch or a special meter from a supply which the instructor keeps at his desk. A modification of this latter procedure is used at Drexel Institute of Technology, where two elementary laboratories are served by a common storeroom placed between them. The window for distributing supplementary apparatus to one of the laboratories can be seen at the right in the photograph of Figure 17, and the door to the storeroom at the left.

In the so-called "free laboratory" each student (or pair of students) selects some problem or problems on which he will devote the major share of his laboratory time with the approval of his instructor. A number of departments of physics are experimenting with various degrees of freedom in the elementary laboratory. Students in the free laboratory at California Institute of Technology (optional as a substitute for the more conventional freshman laboratory work) are granted the freedom of the storeroom to select the instruments and the various materials they need for their problems. The storeroom for a free laboratory must be well supplied with a variety of apparatus and construction materials to accommodate the wide range of problems selected. Furthermore, as at Cali-

Figure 17. Elementary laboratory at Drexel Institute of Technology. Note check-out window at right between laboratory and storeroom.



fornia Institute of Technology, the students must have available a small shop with the necessary tools where they can construct their apparatus under the supervision of a technician.

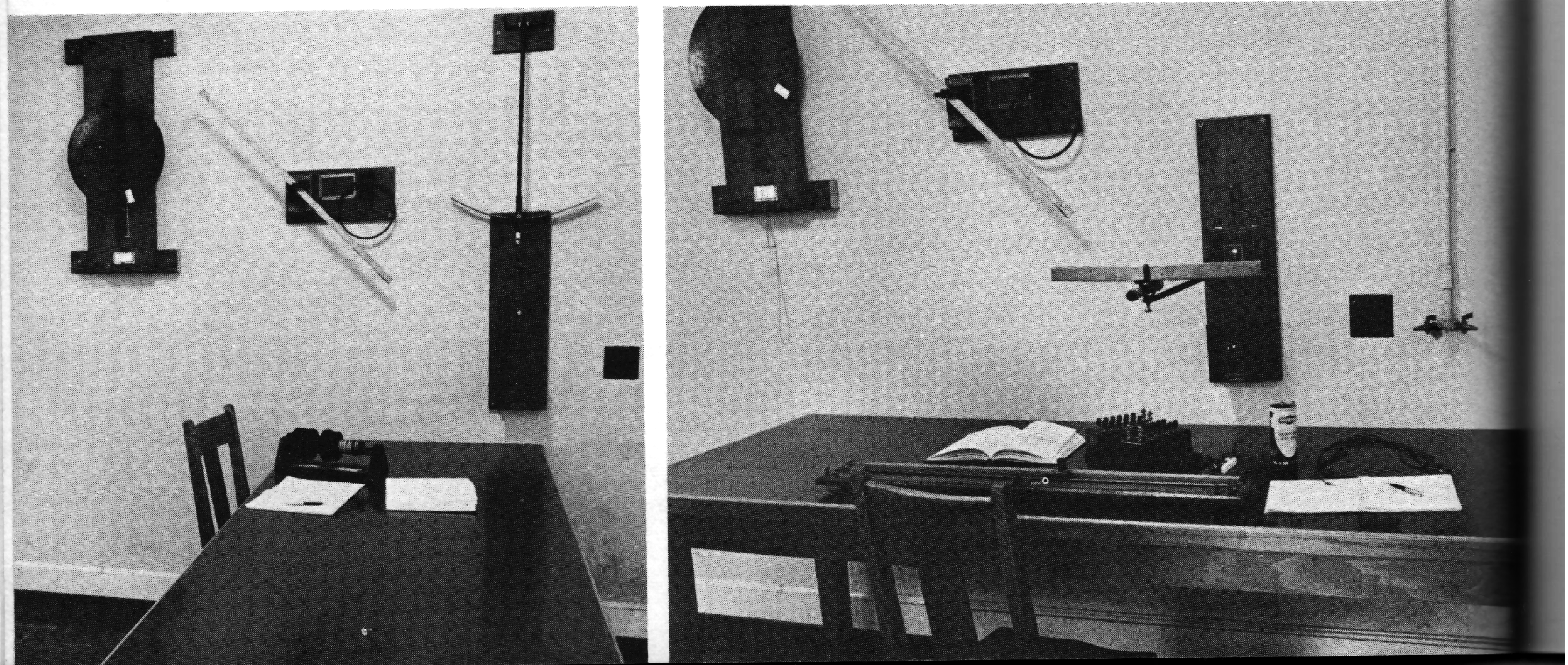
Laboratory Furniture

Excellent laboratory furniture is available from commercial sources, though care must be taken to specify carefully the features desired. On the other hand, a number of colleges and universities build their own furniture, particularly laboratory tables and benches. To judge from the furniture installed in recently constructed buildings, most physics staffs prefer wood rather than steel furniture. However, steel furniture appears to be gaining favor—particularly for open shelving for apparatus and books, and for cabinets and chests of drawers for storing apparatus and small parts. Where laboratory tables with steel bases have been installed, the tops are usually made of some other material. At the Air Force Academy laboratory (Figure 14) the tops of the steel tables are wooden. Tops of laboratory work tables should not be too hard and, for some purposes, they should be non-magnetic and electrically non-conducting.

In general, laboratory tables and benches must be ruggedly constructed, and their tops must be abrasion resistant. Of the surface materials described in Chapter 3, most physics staffs prefer either wood or compressed wood for laboratory tables. Because of their greater resistance to stain and chemical action, stone and compressed asbestos (such as Transite) are commonly used for shelves in the vicinity of sinks, or for the tops of service islands, especially when sinks are mounted in them. A clear light finish is currently preferred for table tops rather than the jet black baked-on surface that was so widely used a few years ago, even though the baked surface is more abrasion resistant. Some departments have sanded off the black surface from their old wooden table tops, and the surface has been given a natural clear lacquer, varnish or plastic finish. The components of most laboratory apparatus show up better against a light surface and, furthermore, the laboratory becomes lighter and is more cheerful.

There appears to be no agreement as to the preferred height for laboratory tables. Both 30- and 36-inch heights are widely used. Stools are commonly used with 36-inch tables. Chairs are sometimes used with 30-inch tables, though stools of appropriate

Fig. 18a, 18b. Two arrangements of laboratory tables in the elementary physics laboratory, University of Wisconsin.



height seem to be preferred. Stools of adjustable height enable the student to select the height which suits him best.

Advantages of Fixed versus Movable Tables

There is a difference of opinion as to whether laboratory tables should be fixed or movable. Those who favor that tables be movable point out the flexibility that this provides. Tables can be put together sideways or end to end, or otherwise placed in the most effective position for a particular experiment. Figure 18 shows two arrangements for a table in the elementary laboratory at the University of Wisconsin. The arrangement shown in 18a is most efficient for certain mechanics experiments using apparatus fastened to the wall (e.g., with the inertia disk or the physical pendulum shown); the arrangement in 18b is more convenient for experiments in electricity requiring the wall galvanometer. Similarly, Figure 11 shows two useful arrangements for the two movable tables in one of the cubicles at Pomona College. Proponents of fixed tables recognize their inflexibility but believe that an over-riding characteristic of a laboratory (particularly an elementary laboratory) should be its orderliness. Movable tables are usually in disarray in laboratories where a number of students are involved. Furthermore, fixed tables provide the stability needed for certain experiments.

Shelves and Drawers in Laboratory Tables

Most instructors believe that it is undesirable to have drawers in the tables of an elementary laboratory. Drawers serve principally as depositories for old paper and wire, and apparatus gets lost in them. At several institutions where tables with drawers were installed in the elementary laboratory, the drawers were subsequently bolted shut. The principal service that a drawer can provide —storing extra books and notebooks so that the top of the table can be kept free of unnecessary articles—can be better provided by an open shelf beneath the table top. (See, for instance, the laboratory tables at Drexel, Figure 17.)

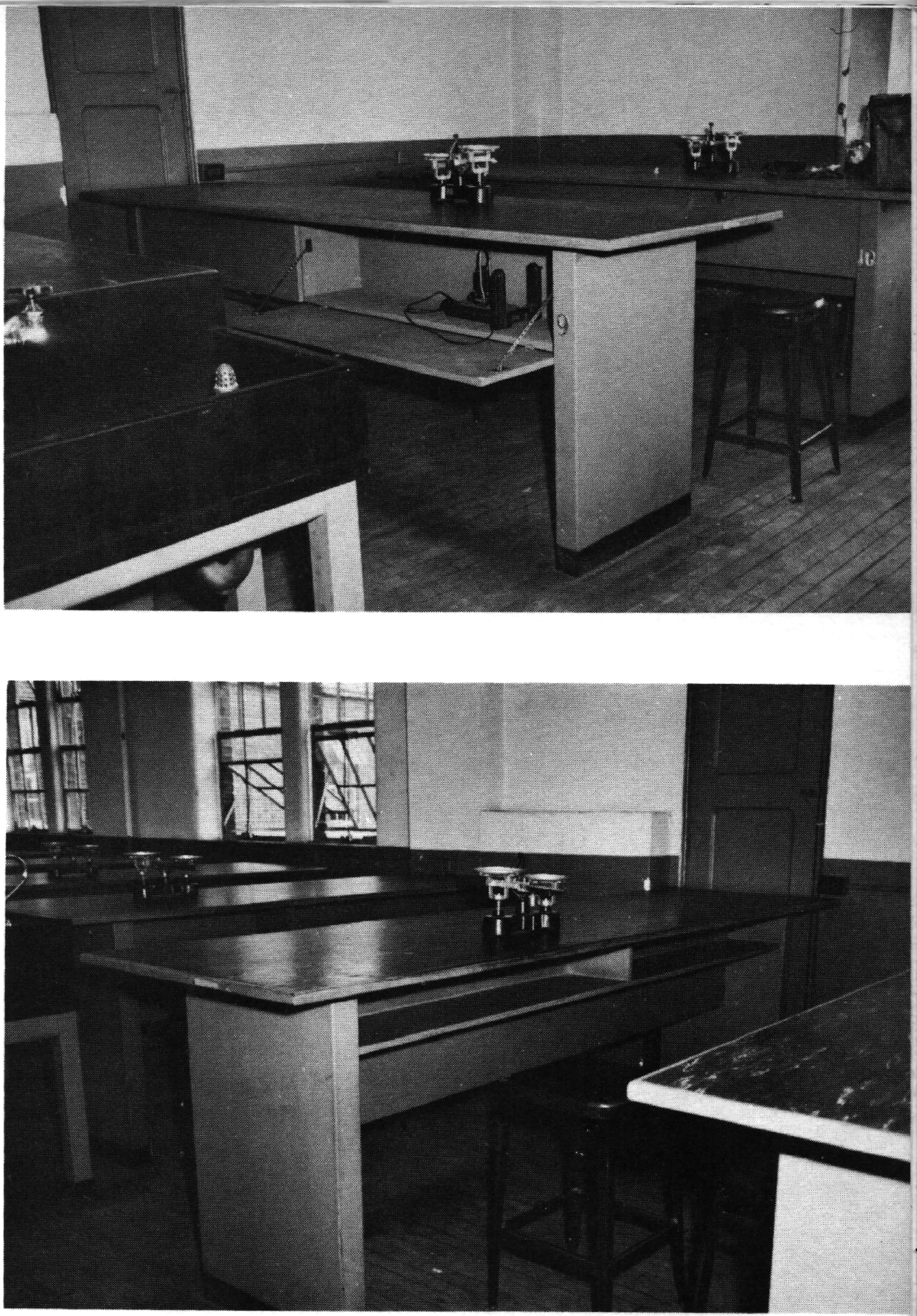


Figure 19. Laboratory tables at Georgia Institute of Technology have space for storing apparatus on one side and books on the other.

The advantage of using laboratory tables for storing apparatus is being tested at Georgia Institute of Technology (Figure 19). Some of the tables in the elementary laboratory have been modified to include a small cabinet with a door that opens down on one side of the table, and open shelves for student books on the other side—the side where students normally work. Swarthmore College was the only other institution we visited which used the space beneath laboratory work stations for storing an appreciable amount of apparatus; steel cabinets completely filled this space. (See Figure 13.) As described earlier, tables are provided in an adjacent area of the laboratory at Swarthmore where students can be seated for writing and making calculations.

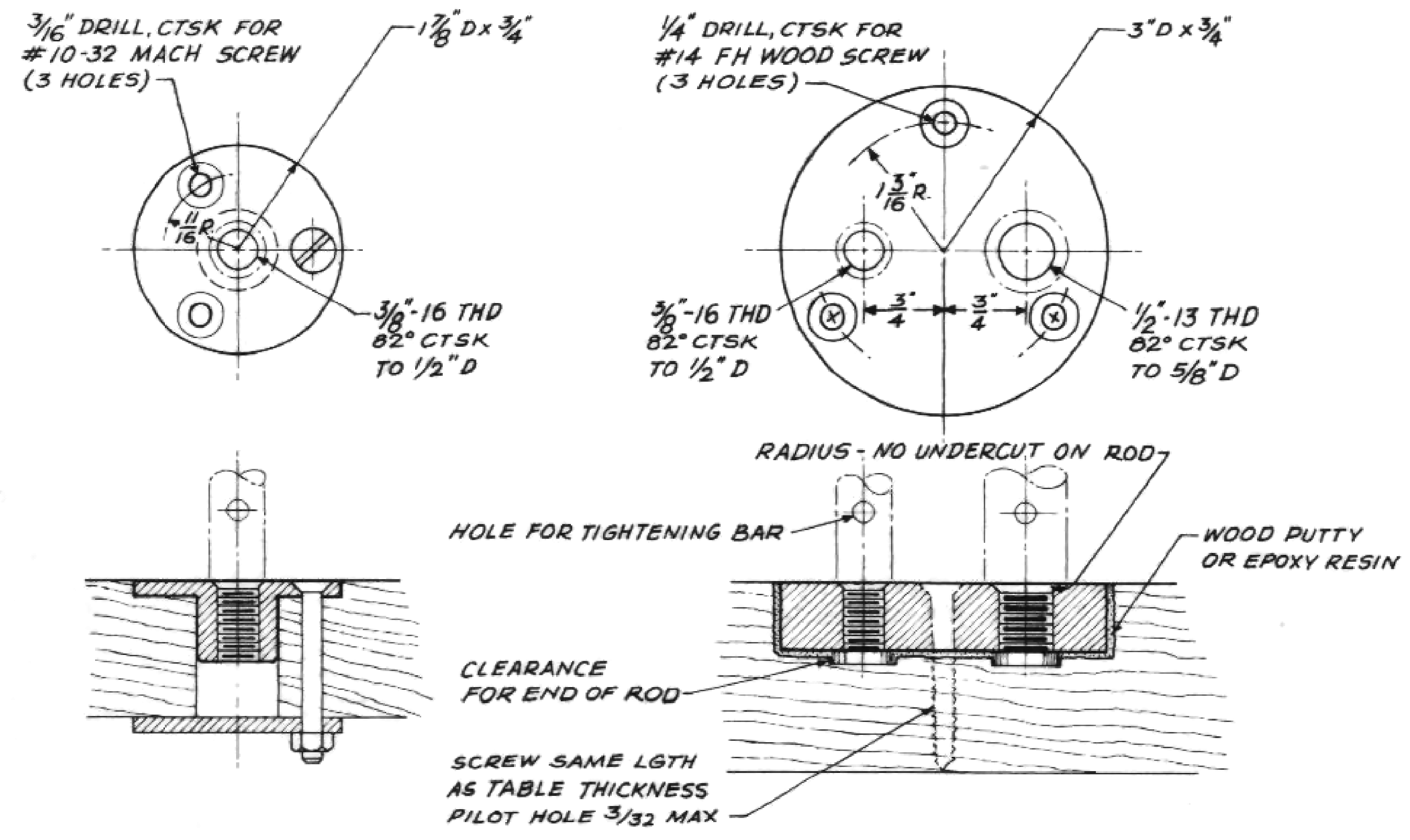

3/16" DRILL, CTSK FOR
#10-32 MACH SCREW
(3 HOLES)
1 7/8" D x 3/4"
11/16 R.
3/8"-16 THD
82° CTSK
TO 1/2" D
1/4" DRILL, CTSK FOR
#14 FH WOOD SCREW
(3 HOLES)
3" D x 3/4"
1 3/16 R.
3/8"-16 THD
82° CTSK
TO 1/2" D
3/4
3/4
1/2"-13 THD
82° CTSK
TO 5/8" D
RADIUS - NO UNDERCUT ON ROD
HOLE FOR TIGHTENING BAR
WOOD PUTTY
OR EPOXY RESIN
CLEARANCE
FOR END OF ROD
SCREW SAME LGTH
AS TABLE THICKNESS
PILOT HOLE 3/32 MAX

Figure 20a. Cross-section drawings of steel inserts for supporting vertical rods, installed in laboratory tables at the University of Florida (left), and at Massachusetts Institute of Technology (right).

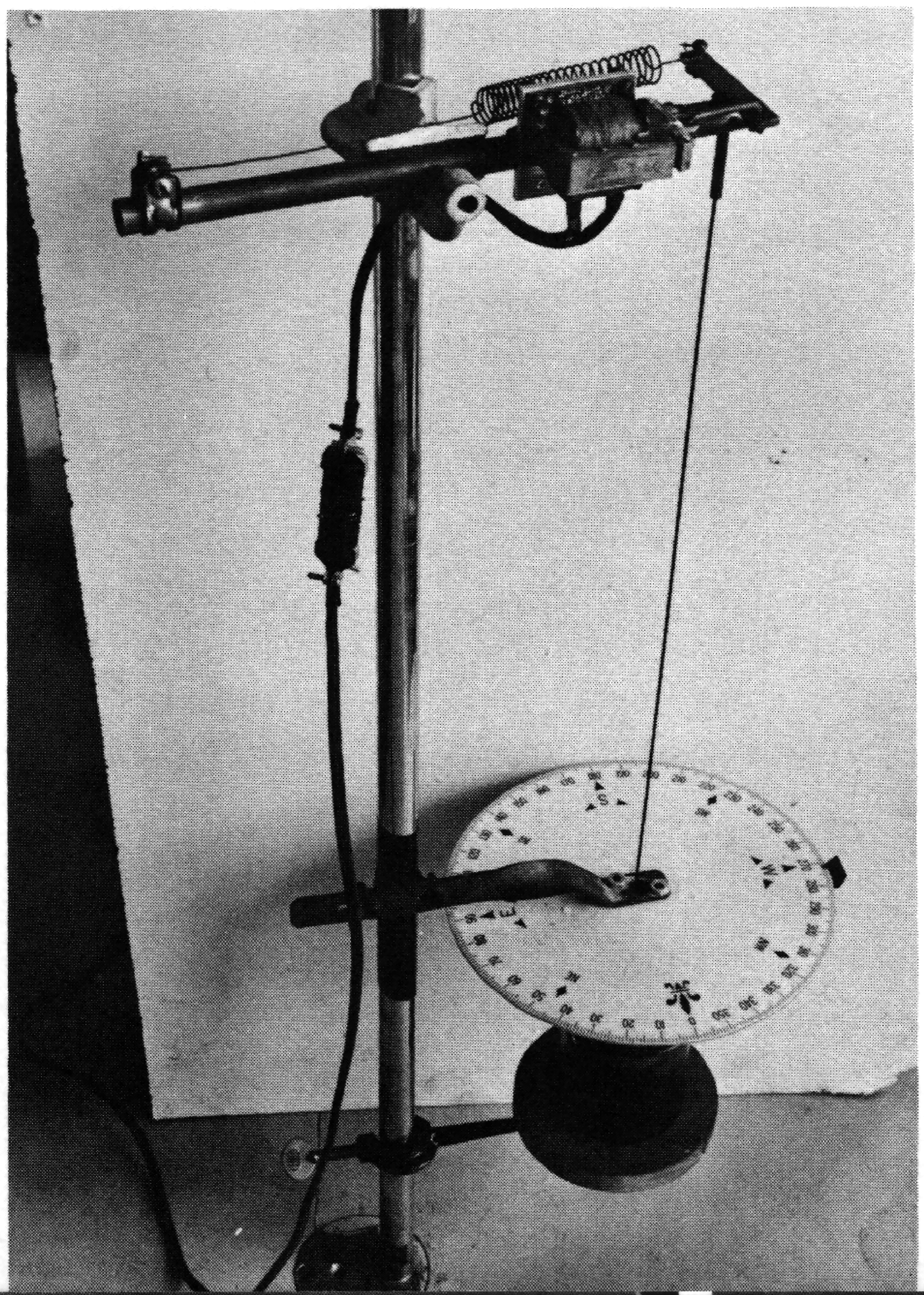


Figure 20b. Forced damped harmonic motion apparatus supported by steel insert in laboratory table at Massachusetts Institute of Technology. Note that insert is designed to take rods of two different sizes.

Methods of Mounting Apparatus

It is frequently necessary to secure apparatus to the top of laboratory tables by using a C-clamp, or to support a vertical rod at the edge of a table by means of a special clamp. For both purposes the table top must not only be sturdy but it must have an adequate overhang—at least 2½ inches. Most standard commercial tables fail in this latter respect. At a number of new laboratories standard tables with an inadequate overhang were supplied; care had not been taken to specify the minimum acceptable overhang.

Metal inserts, mounted flush with the top of a laboratory table, are also widely used for supporting vertical rods. Inserts that are tapped to take a threaded rod are preferable to those that take a tapered rod. Inserts that are simply attached to the table by wood screws are unsatisfactory since they readily loosen with continued use. Two alternative and satisfactory types of inserts and the preferred methods of fastening them to the table are sketched in Figure 20.

Some institutions provide a permanent structure of some kind on their laboratory tables for supporting apparatus. Inverted L-shaped supports, fabricated of hollow steel tubing are to be used in the elementary laboratories in the new wing of the physics building at the University of Texas. The structure of the "L" and how it will be attached to each table is shown in Figure 21.

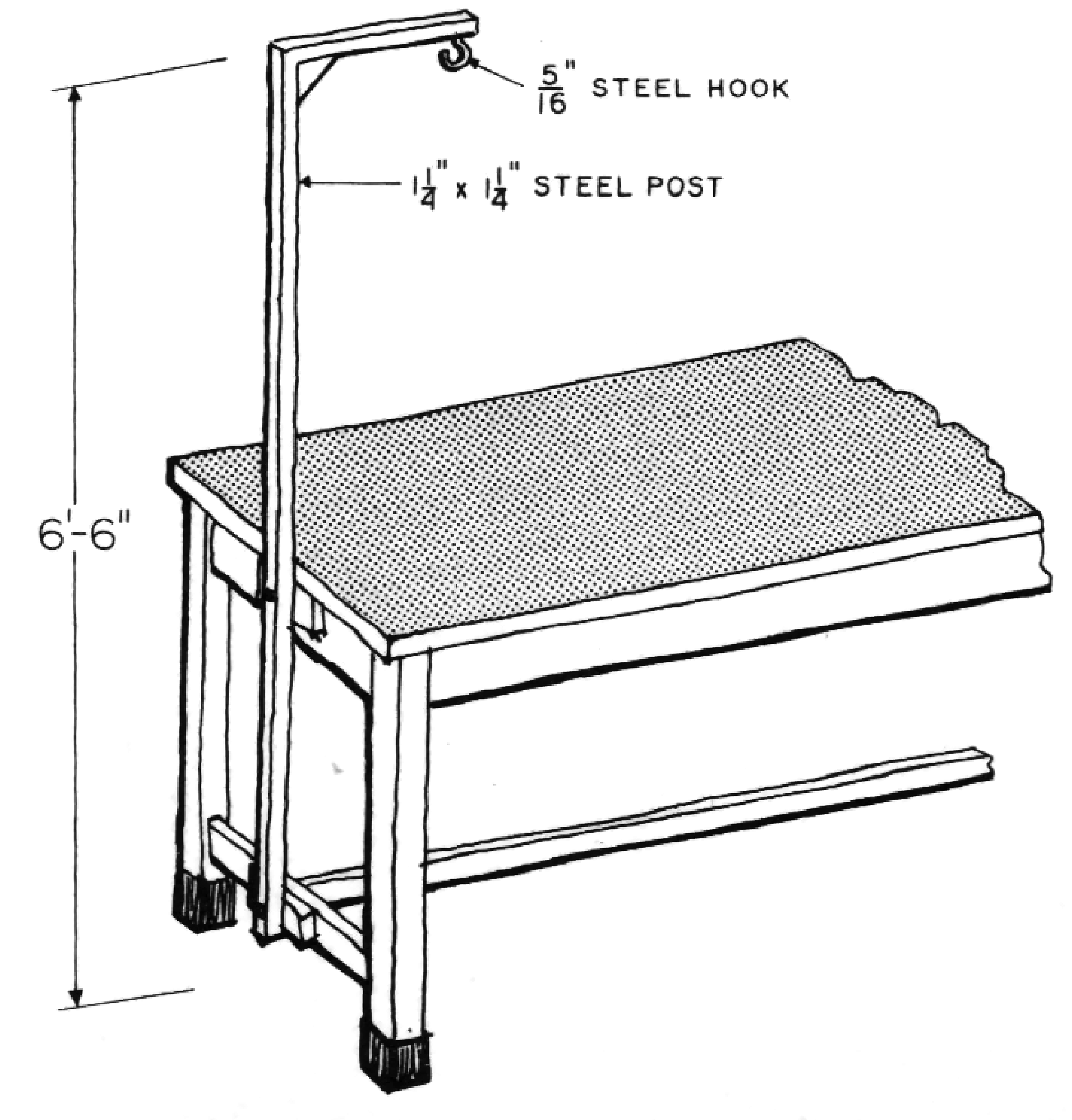

5/16" STEEL HOOK
1 1/4" x 1 1/4" STEEL POST
6'-6"

Figure 21. Drawing of "L-support" attached to elementary physics table, University of Texas.

These supports are patterned after wooden supports which proved useful for a number of years in laboratories in the main building at Texas. The overhead supports on some of the tables at Northeastern University should also be noted (Figure 8), as well as the more elaborate frame and shelf on the tables at Illinois Institute of Technology (Figure 10).

Laboratory walls are also widely used for mounting apparatus. Most of the photographs in this chapter give evidence of this. Note in particular, the extensive use that is made of metal channels (Unistrut) inserted flush with the side walls at El Camino College (Figure 15). One channel runs around the side wall close to the ceiling and a second, about 8 feet off the floor. A 12-inch plank extending the length of the room on each side serves to support galvanometer mounts as well as other apparatus. Furthermore, metal channels are set in the ceiling for still greater versatility. (We saw the ceiling channels in one of the laboratories used to support a half dozen bowling balls for a collision experiment.) Wooden boards bolted to the ceiling are also useful for supporting apparatus.

Figure 22 shows how apparatus is supported from steel plates mounted flush with the side walls in the teaching laboratories at Oberlin. (The upper plate is partially obscured by paint.) Holes are drilled in the plate as needed and tapped to take machine screws for supporting apparatus.

Figure 23 shows how effectively boards are used for mounting apparatus in the Freshman Laboratory at Massachusetts Institute of Technology. A vacuum line and an experimental tube for a molecular beams experiment are both mounted as shown, together with the necessary utilities. Each vacuum line and associated pump serves four stations, and there are four such lines for a total of 16 stations. The board shown consists of three ¾-inch hardwood boards, wood-screwed to vertical cleats which were previously attached to the masonry wall by lag screws and expansion shields. By mounting the boards on cleats away from the wall, other apparatus

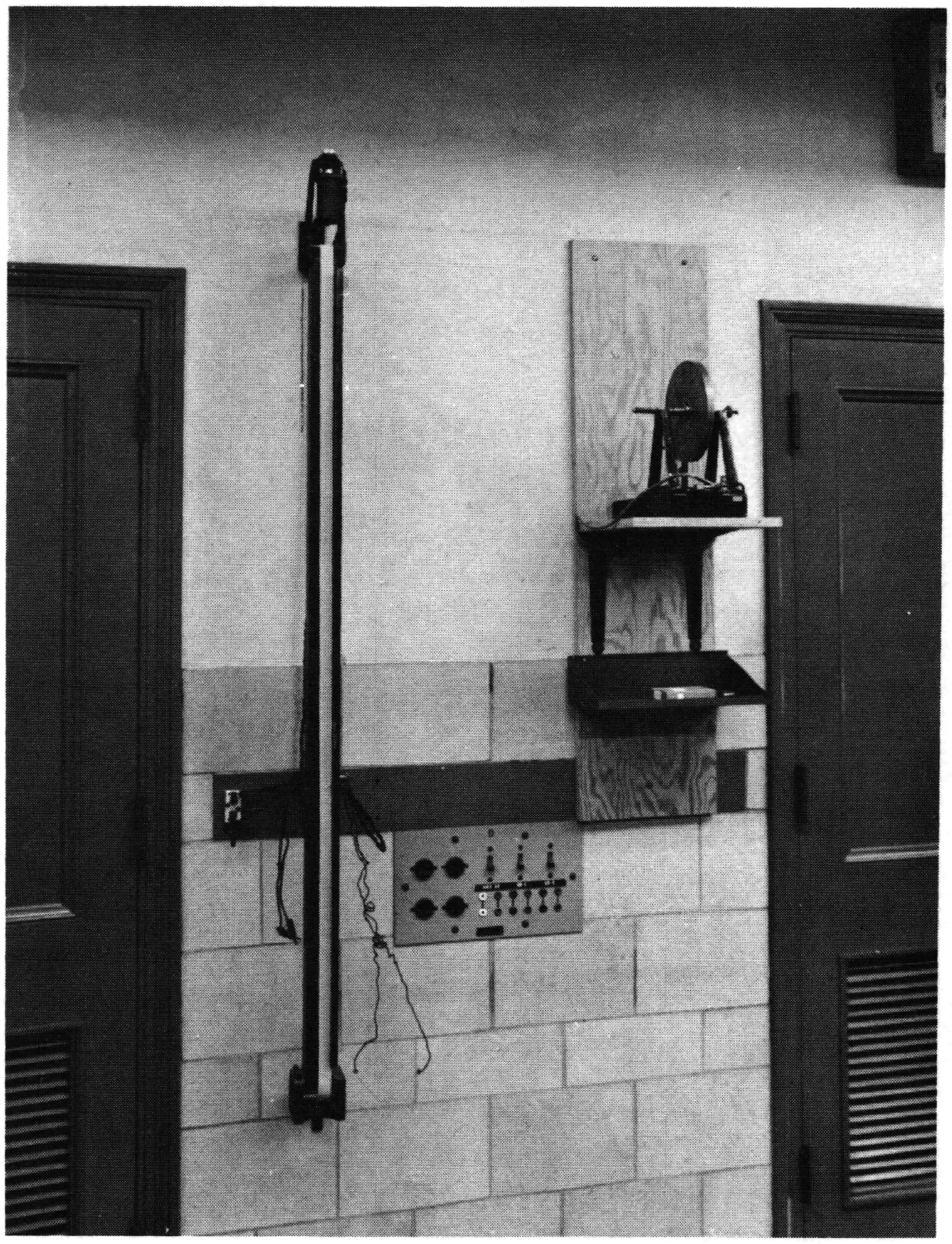
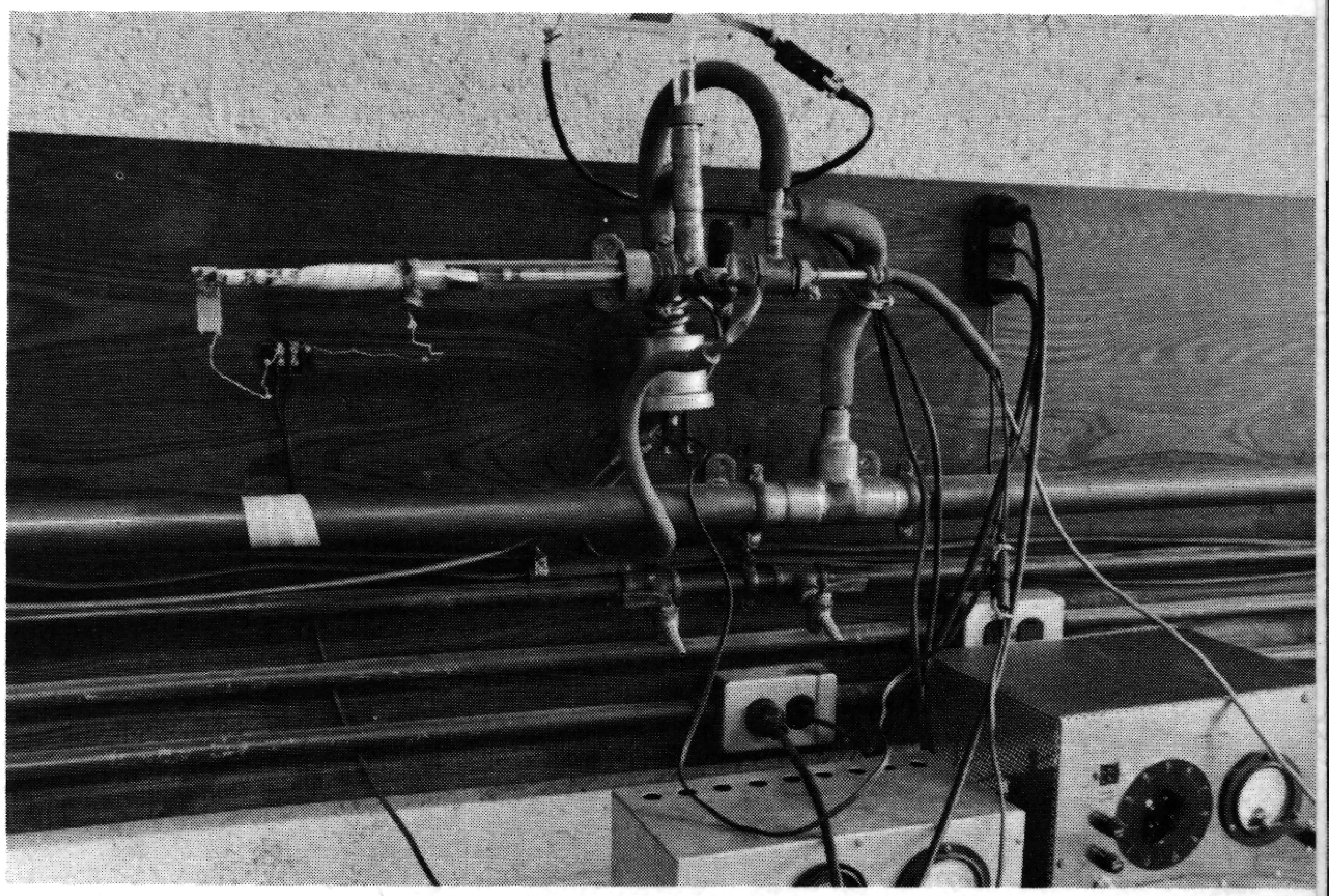


Figure 22. Steel plates in the wall, drilled and tapped to take machine screws, support laboratory apparatus at Oberlin College.

Figure 23. Wide hardwood boards mounted on cleats on the wall support a vacuum line and utilities for a molecular beams experiment in the freshman physics laboratory at Massachusetts Institute of Technology.



can be hung from or clamped to the top of the boards more conveniently. The cleats should not come quite to the top of the boards so that clamps can be placed at any point. Furthermore, if the boards are in short lengths, individual sections can readily be replaced when they become too filled with holes or otherwise become unserviceable.

Chalkboards and Tackboards

All physics laboratories require chalkboards. However, the amount of wall space devoted to them varies considerably—from a minimum area of about 4 by 6 feet up to that at the new Air Force Academy where chalkboards almost cover three side walls of each laboratory (Figure 14). The chalkboards along the side walls at the Academy are more than 5 feet in height; those at the front wall extend from floor to ceiling and are movable; they can be rolled sideways and thus serve as doors to a closet in which the sub-distribution panel for dc power is located and in which frequently used apparatus is stored. Chalkboards in the laboratory are useful for recording temporary instructions, and for working problems and clarifying theory either on the part of the instructor or by small groups of students working independently.

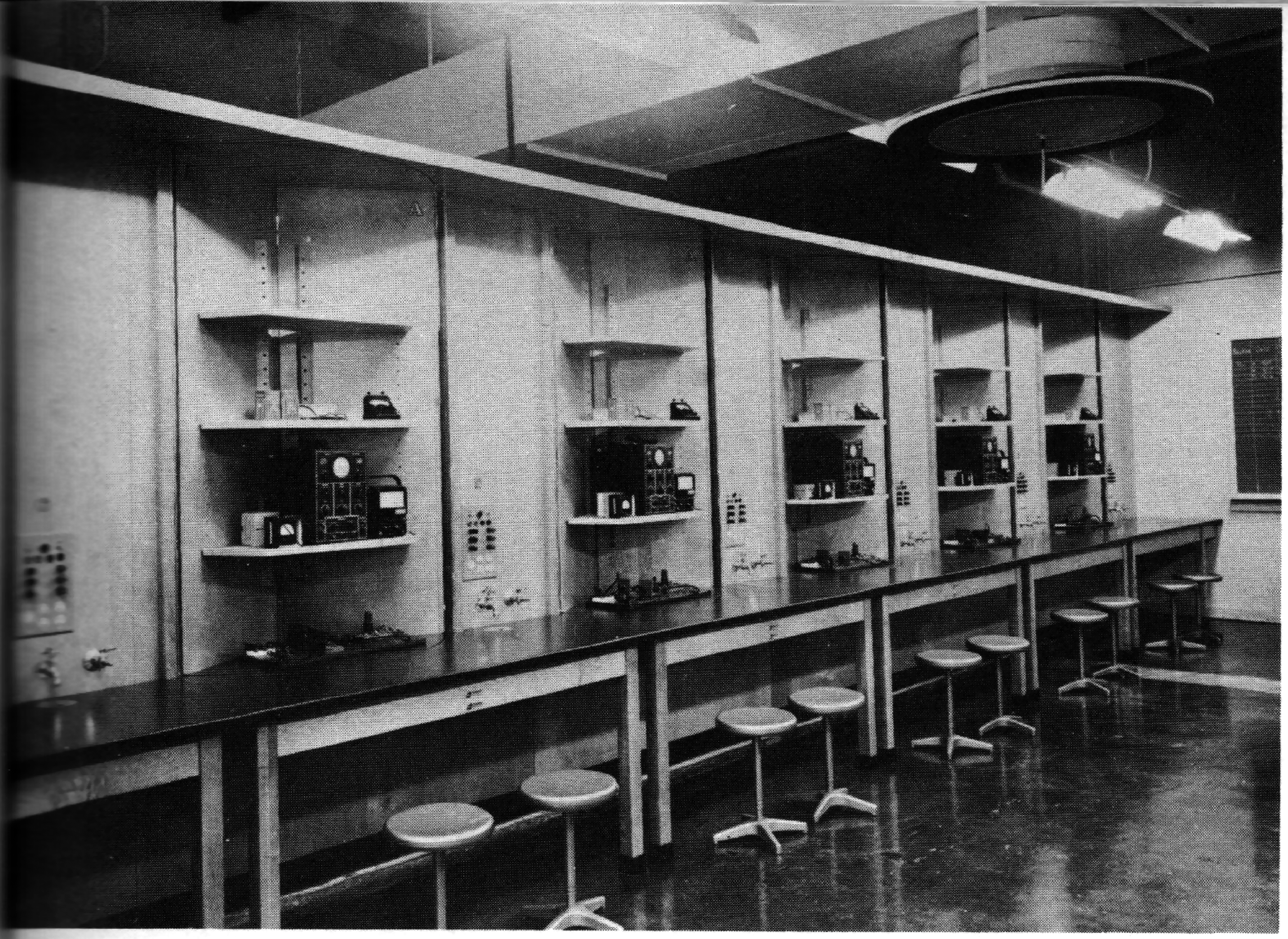
Most elementary physics laboratories also have a tackboard mounted near the entrance to the laboratory. It is useful for posting such things as schedules, charts, physical constants that may be pertinent to experiments under way, and other items less temporary than those suitable for posting on the chalkboard. A tackboard for such purposes need be no larger than about 3 x 4 feet.

Coat and Book Racks

Outer wraps and extra books left on laboratory tables get in the experimenter's way. Some other more adequate provision should be made for their disposition. Shelves and hooks may be provided in the corridor or preferably, in the laboratory, since students prefer that their belongings be not out of sight. Clothes racks which take clothes hangers are more useful than hooks. Metal clothes racks which have one or two shelves for books are available commercially, either as free standing portable units or for wall attachment. A suggested set of shelves for books and notebooks and a clothes rack both appear in the laboratory layouts sketched in Figure 1.

The Roto Lab

The Roto Lab is a new type of laboratory furniture which makes it possible to change from one laboratory setup to another in a minimum of time so that different laboratory sections can be scheduled in successive periods. The device is essentially a "lazy susan" which can hold apparatus for three different experiments. The photographs of Figure 24, taken in one of the elementary physics laboratories at the Undergraduate Division of the University of Illinois in Chicago, shows two methods of installing the Roto Lab. The center section of each unit is 4 feet in diameter and is divided into three compartments which can be equipped with adjustable shelves. The unit is mounted so that the circular base is flush with the laboratory table top to form a continuous working surface. Figure 24a shows several units placed side by side to form a continuous wall a short distance from one side of the laboratory. Outlets for water, air and electric power are located on the wall between the units. As shown in 24b, two of the compartments in each unit can be serviced from a storage area in back while one is in use. The alternative "island" arrangement of 24c shows two units side by side with one of them facing in the opposite direction. The Roto Lab units can either be turned by hand or by electric power. They are manufactured by Hamilton Manufacturing Company, Two Rivers, Wisconsin; and were developed by O. L. Railsback and H. M. Skadeland of the University of Illinois, Undergraduate Division, Chicago, Illinois.



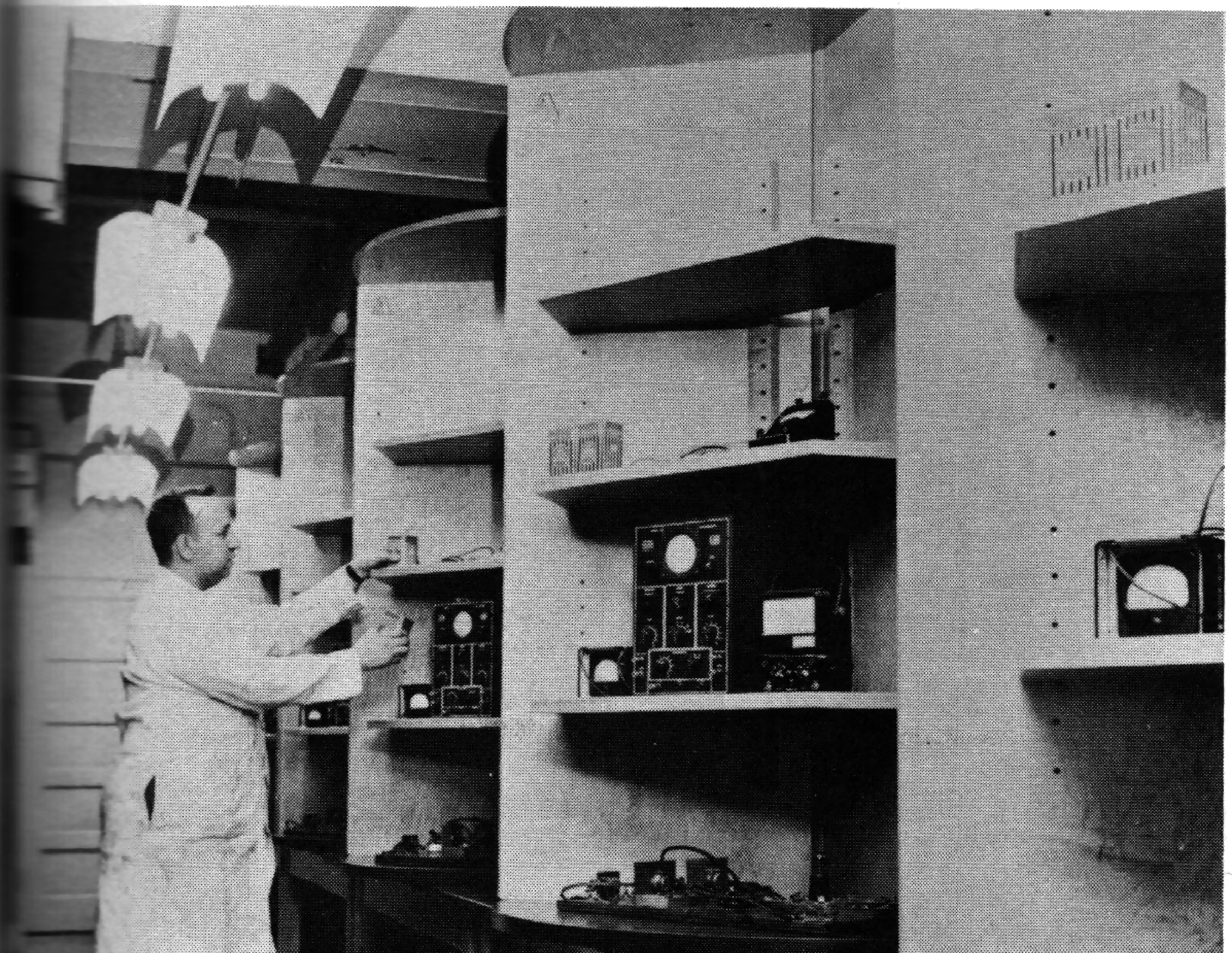
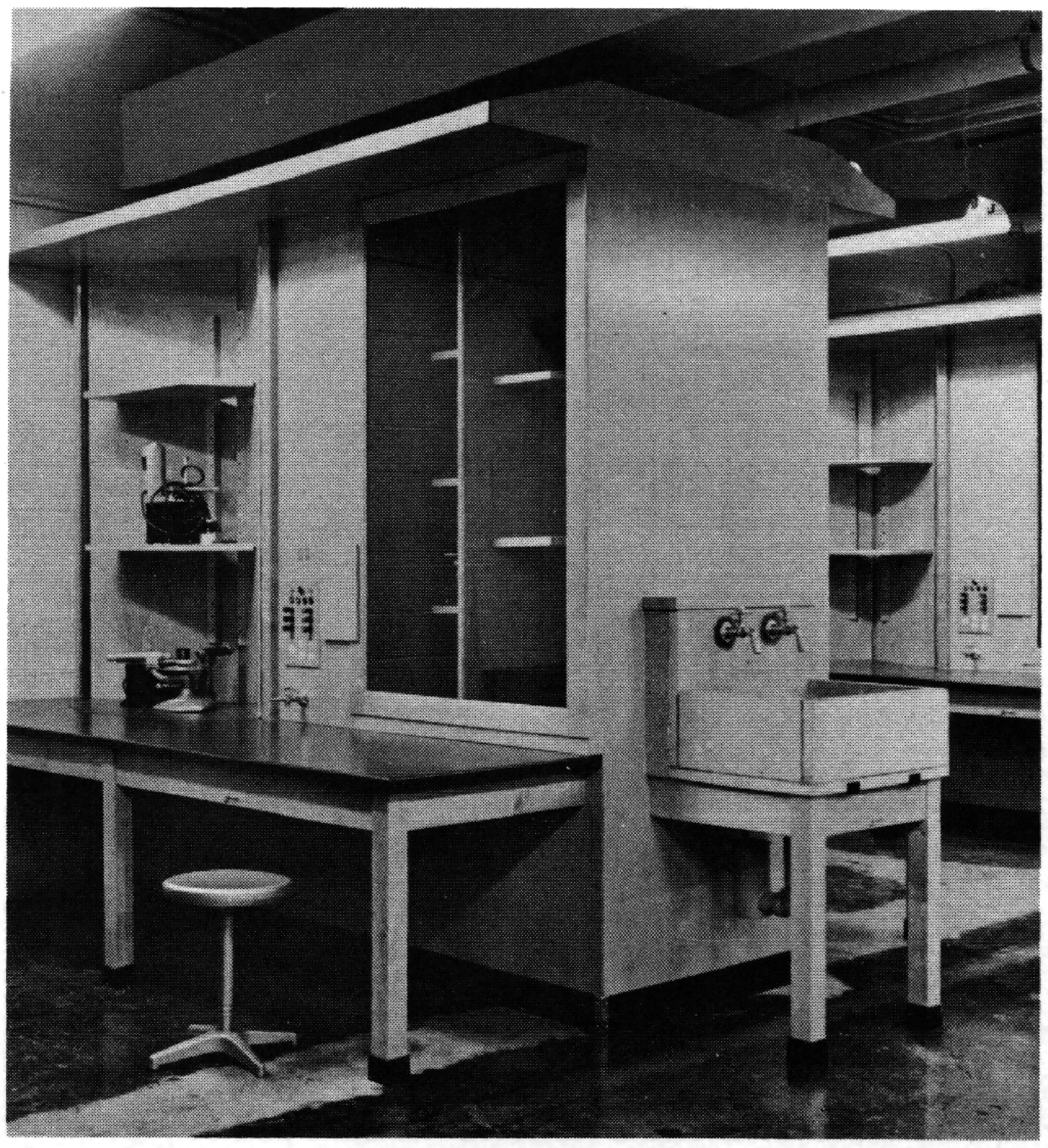


Figure 24. "Roto Lab" at the University of Illinois, Undergraduate Division, Chicago. Prototypes constructed by the Hamilton Manufacturing Company, Two Rivers, Wisconsin. Photographs show several units along one side of laboratory (above); servicing of units from storage area (left); alternative arrangement of two units (below).



ADVANCED TEACHING LABORATORIES

Space Requirements

Advanced teaching laboratories require more work space per student than elementary laboratories since a good deal more equipment is needed for advanced experiments. Roughly twice as much table top area is commonly provided—an average of from 15 to 20 square feet per student. Furthermore, since students usually work on advanced experiments singly rather than in pairs, fewer students can be accommodated in a room of a given size.

Types of Laboratories

The number and diversity of advanced teaching laboratories varies considerably from institution to institution. At large institutions, separate laboratory rooms are usually provided for advanced work in the various subject matter areas of physics. Where fewer students are involved individual laboratories serve several areas, normally in different semesters. At some institutions advanced laboratory courses are not classified in terms of their subject matter but rather by level of sophistication. For instance, at Case Institute of Technology, after finishing a two-year course in General Physics, students may enroll in a Junior Laboratory and subsequently in a Senior Laboratory. Neither laboratory is correlated with a particular lecture course.

The arrangements of the rooms in the two laboratories at Case (Figure 25) illustrate two points of view with respect to advanced laboratories. There are those who desire that the advanced laboratory area be subdivided into relatively small working areas—separate rooms where usually no more than two students work at a time—as in the Senior Laboratory at Case. It is believed that such an arrangement creates a "research atmosphere and leads to independent thinking" and that "students can get more done in a given laboratory period." Others desire that the advanced laboratory have, at least in part, a fair amount of open area—a room large enough to accommodate several different experiments at the same time—as in the Junior Laboratory at Case. The distractions

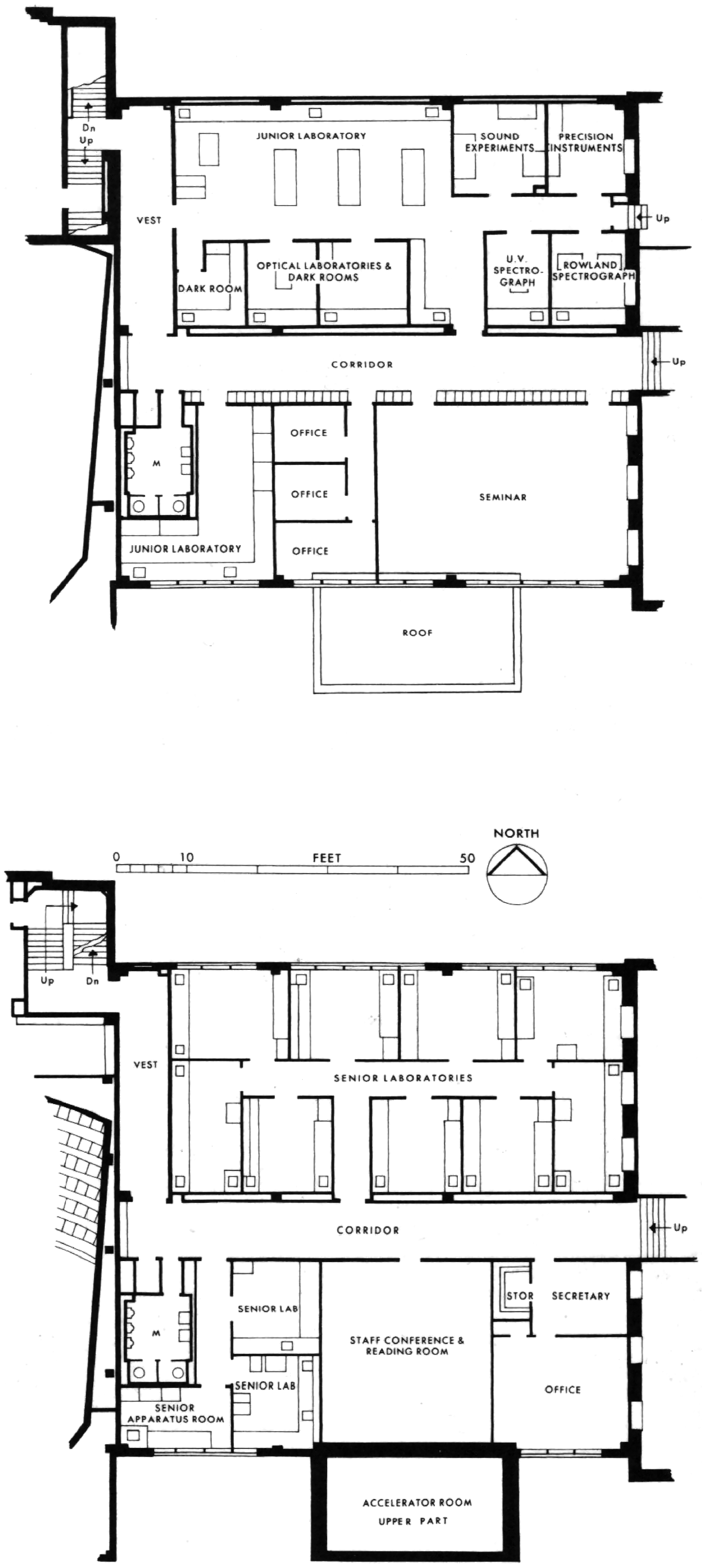

Dn
Up
JUNIOR LABORATORY
SOUND EXPERIMENTS
PRECISION INSTRUMENTS
Up
VEST
DARK ROOM
OPTICAL LABORATORIES & DARK ROOMS
U.V. SPECTRO-GRAPH
ROWLAND SPECTROGRAPH
CORRIDOR
Up
OFFICE
M
OFFICE
SEMINAR
JUNIOR LABORATORY
OFFICE
ROOF
0
10
FEET
50
NORTH
Up
Dn
VEST
SENIOR LABORATORIES
CORRIDOR
Up
SENIOR LAB
STOR
SECRETARY
M
STAFF CONFERENCE & READING ROOM
SENIOR LAB
OFFICE
SENIOR APPARATUS ROOM
ACCELERATOR ROOM UPPER PART

Figure 25. Floor plans of laboratories at Case Institute of Technology. Senior Laboratory is subdivided into small working areas; Junior Laboratory is organized around an open area with side rooms as adjuncts. Small, Smith, Reeb & Draz, Architects, Cleveland, Ohio.

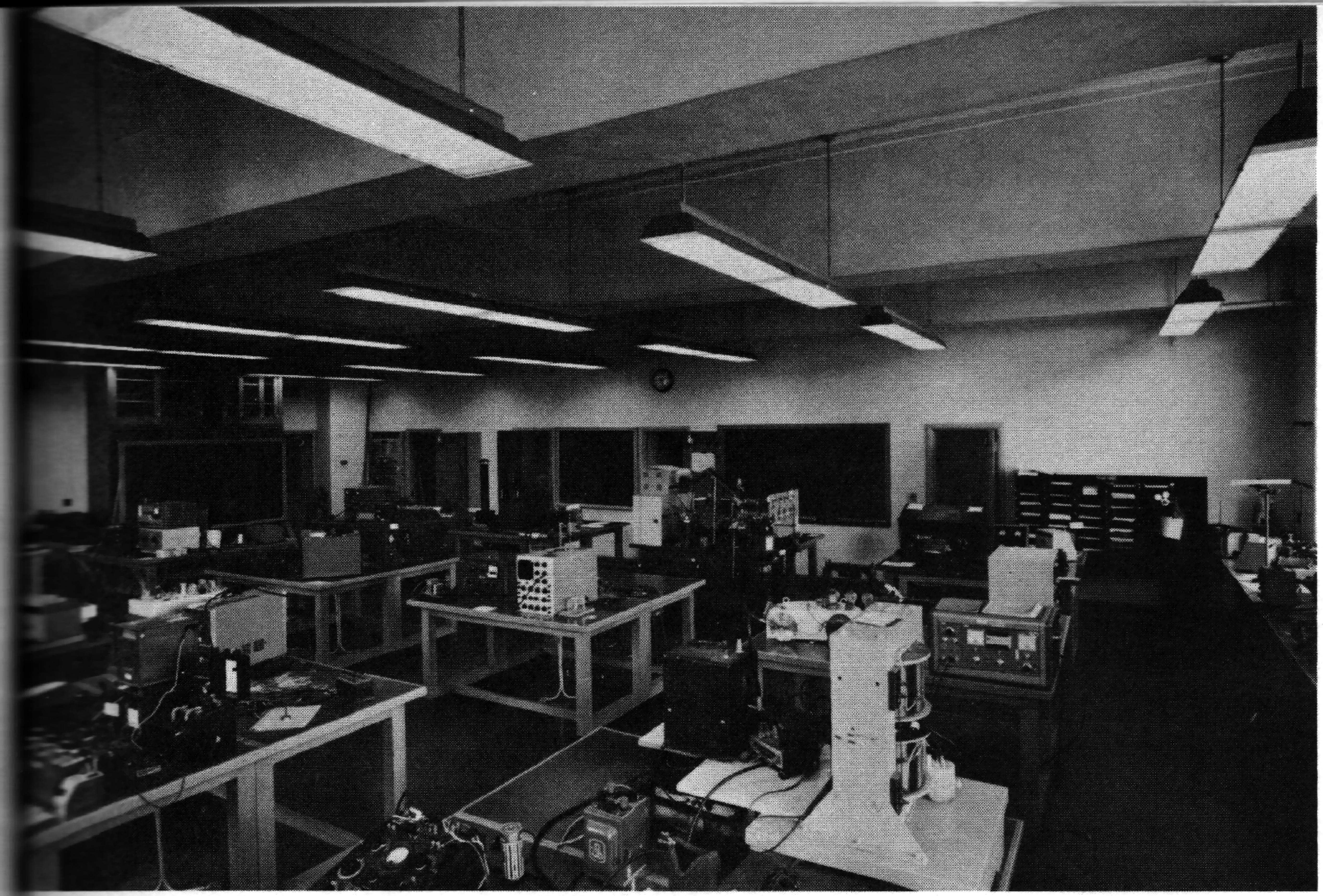


Figure 26. Modern Physics Laboratory at the University of California (Berkeley). Note doors to side rooms in background.

that may result are believed to be more than offset by the positive help and stimulus that one group can give another. The arrangement does not preclude the need for a number of smaller rooms for the isolation of experiments in light or sound or precision of measurement; these are also provided as adjuncts to the Junior Laboratory at Case.

The Modern Physics Laboratory at the University of California (Berkeley) utilizes a large open room (about 38 by 50 feet). The apparatus for each experiment is left set up throughout the semester on one of 12 tables as shown in Figure 26. Also note in the photographs the doors to four side rooms; three are darkrooms (each about 8 by 9 feet), and the fourth is a shop and apparatus storeroom (about 8 by 25 feet). See also the floor plan in Chapter 4, Figure 1.

Advanced laboratories which are devoted to certain subject matter areas have certain characteristics in common. For example, laboratories in optics are commonly provided with small side rooms for experiments requiring darkness, as in the Optics Laboratory at the University of Georgia (Figure 27). Similar side rooms of various size can be seen in other floor plans in Chapter 4. To accommo-

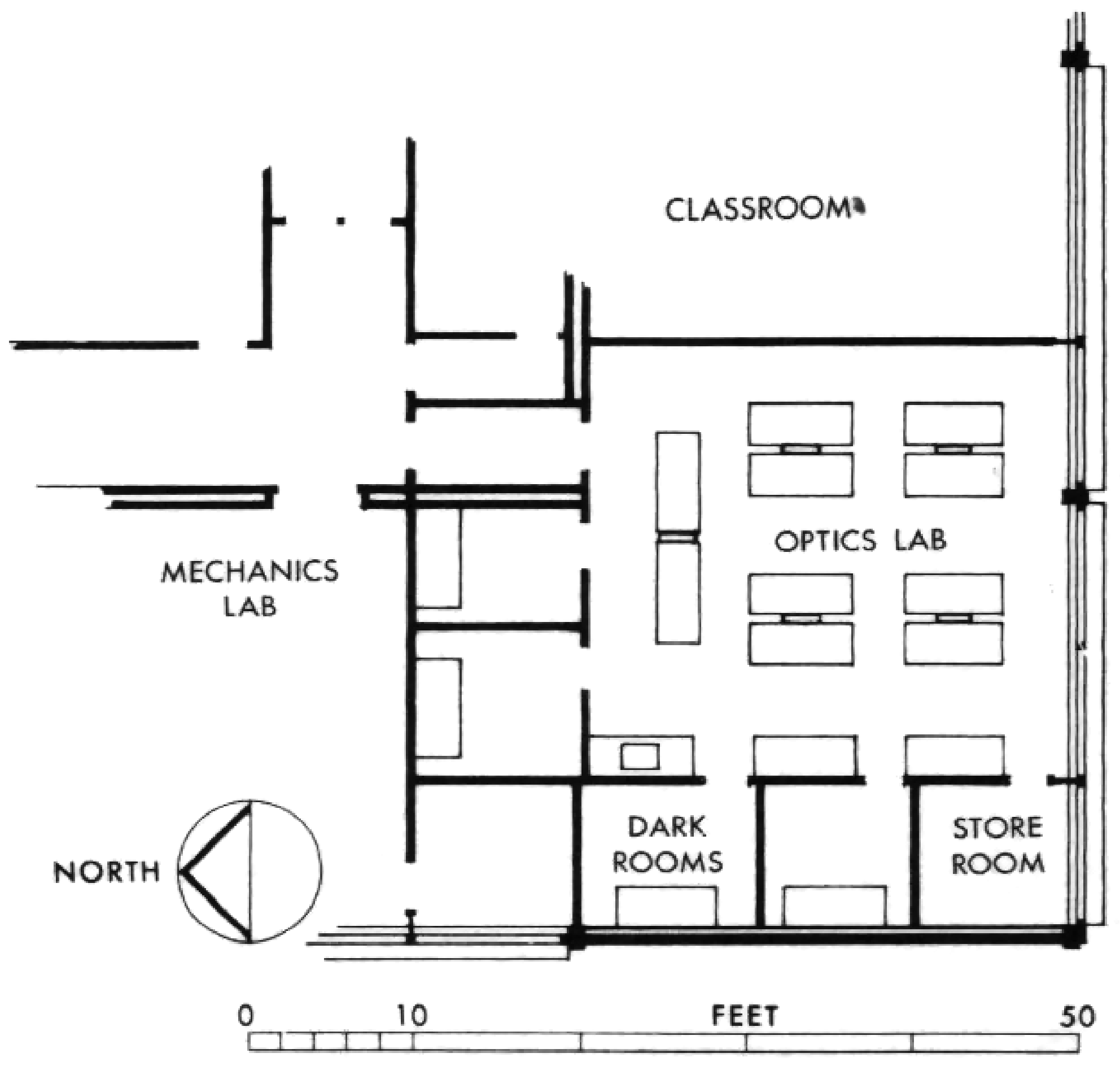
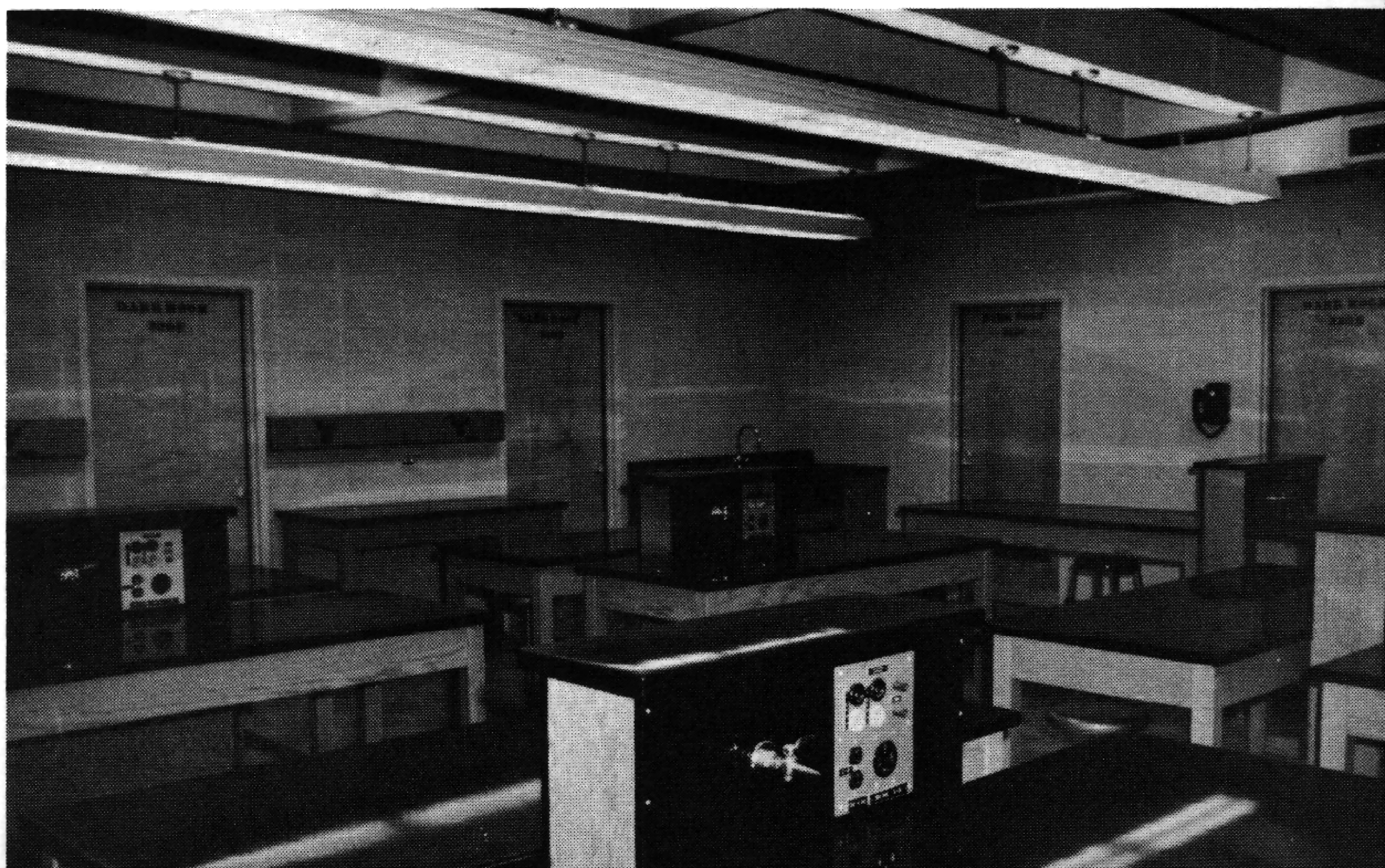


Figure 27. Optics Laboratory at the University of Georgia (Chapter 4, Figure 4). Note dark rooms around two sides of laboratory.



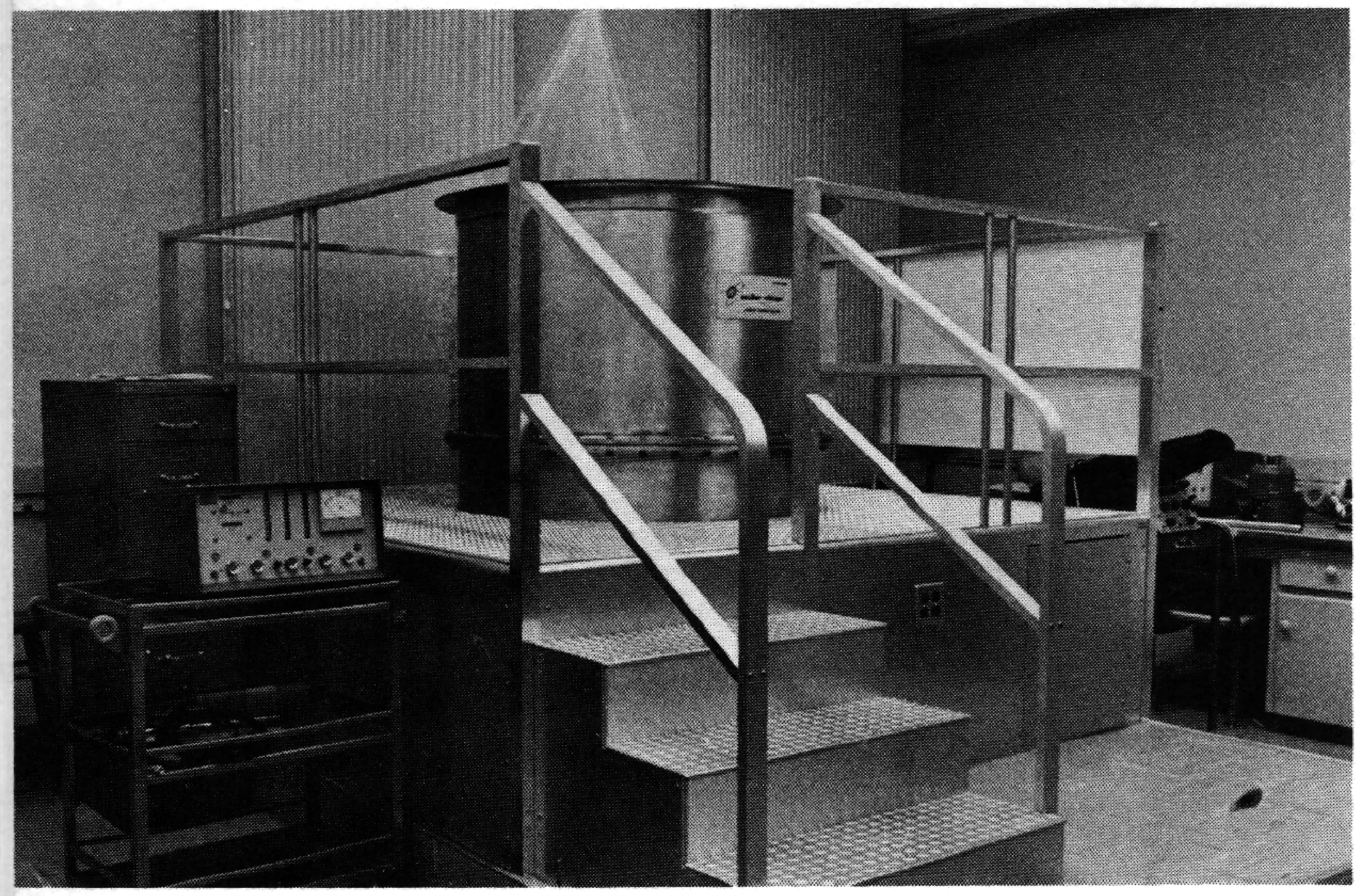


Figure 28. Subcritical reactor in the Nuclear Physics Laboratory at Occidental College.

date a longer optical path, an opaque window which can be opened is frequently installed between adjacent side rooms. One of the small rooms in an optics laboratory is commonly equipped as a darkroom for photographic work, such as processing spectrographic plates. Since at many institutions, the optics laboratory must double for other advanced laboratory work in off semesters, some of the small side rooms should be supplied with a sink and running water as well as with the other utilities. All side rooms should be ventilated, with individual fans if necessary. Light-tight louvers in doors can be used for exhaust or supply of air.

Advanced laboratory work in nuclear physics at Occidental College is supported by the subcritical reactor shown in Figure 28.

Equipment in the Advanced Laboratory

Wall benches that are fixed in position are widely used in advanced laboratories, together with tables which are movable to provide the required flexibility. Although tables and benches are usually 36 inches high, additional 30-inch tables with chairs are frequently provided for making calculations or writing reports. Cabinets for storing apparatus are commonly placed at intervals beneath wall benches, leaving kneehole spaces at designated work stations. Much of the apparatus used in advanced laboratories is stored within the laboratory itself—in under-bench cabinets and in free-standing cases, though adjacent storerooms are usually available as well. Some major or frequently used apparatus is commonly left fixed in position where it is expected to be used; this includes such items as electromagnets, spectrographs, vacuum systems, and wall galvanometers. See Figure 29 for an installation of galvanometers in a side room off the Electrical Measurements Laboratory at Drexel Institute of Technology. Figure 30 shows how a high voltage power supply used for experiments in the Modern Physics Laboratory at Swarthmore is permanently mounted near the ceiling. Note how Unistrut in the concrete beam serves for this purpose.

Services in the Advanced Laboratory

The requirement of advanced laboratories for electrical and mechanical services varies somewhat with the nature of the laboratory. All laboratories require a generous supply of 120-volt 60-cycle ac power. Three-phase ac may be required in some areas and is easily provided since electric power is normally being installed as 4-wire 120/208 volts 3-phase ac. Water, gas, and compressed air are also required for many purposes. These several services are usually furnished in advanced laboratories in the same manner as in the elementary laboratories. At least one general purpose sink is usually installed in each laboratory. Where the utilities are distributed through service islands along the wall of the laboratory (as at Pomona College, Figure 11) additional sinks (cup sinks) are usually installed in the top of the island or mounted on top of it; ac and dc outlets from the 120-volt dc house generator and central distribution system (if any) are either mounted in panels on the side of the island or in turrets on top of it.

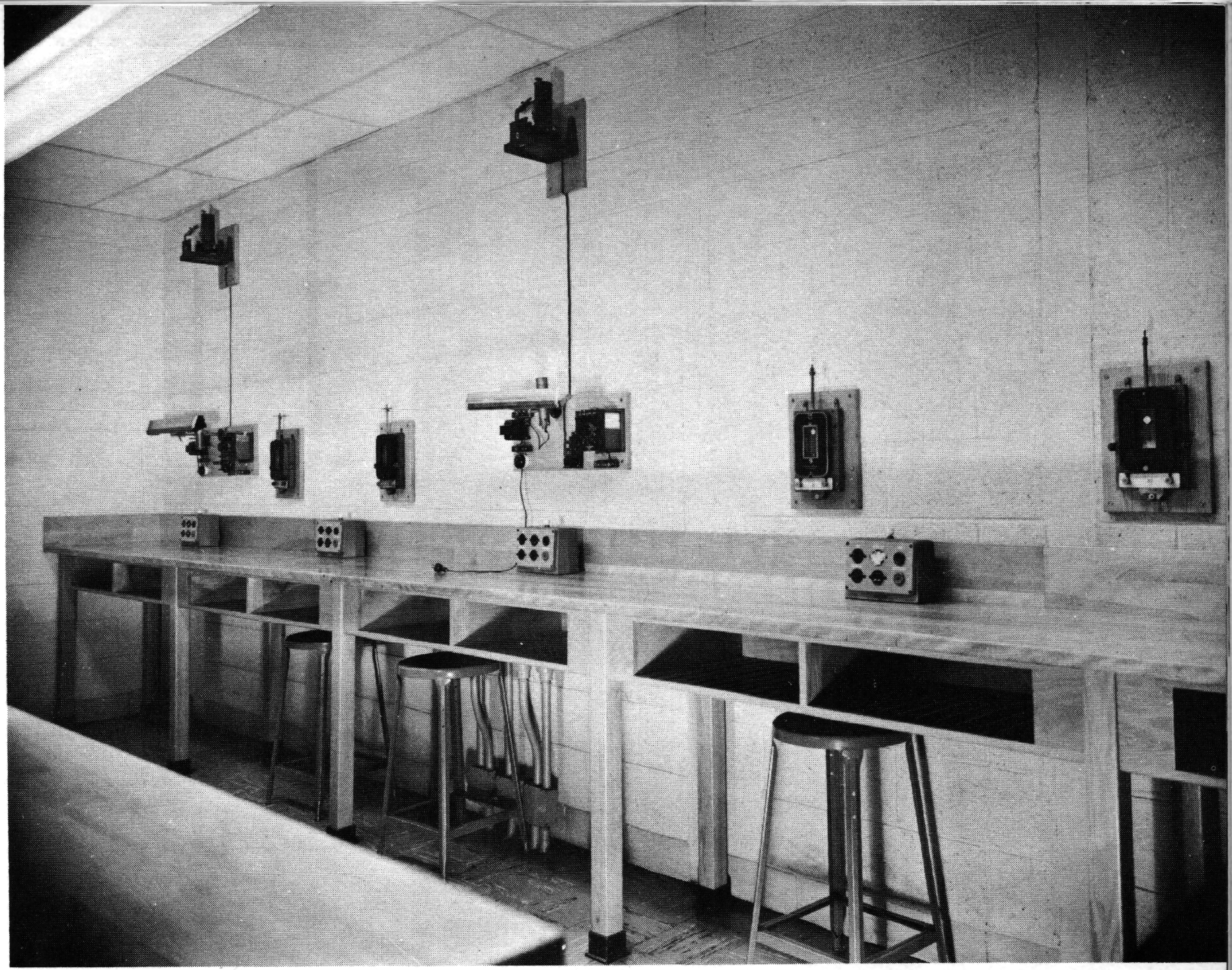
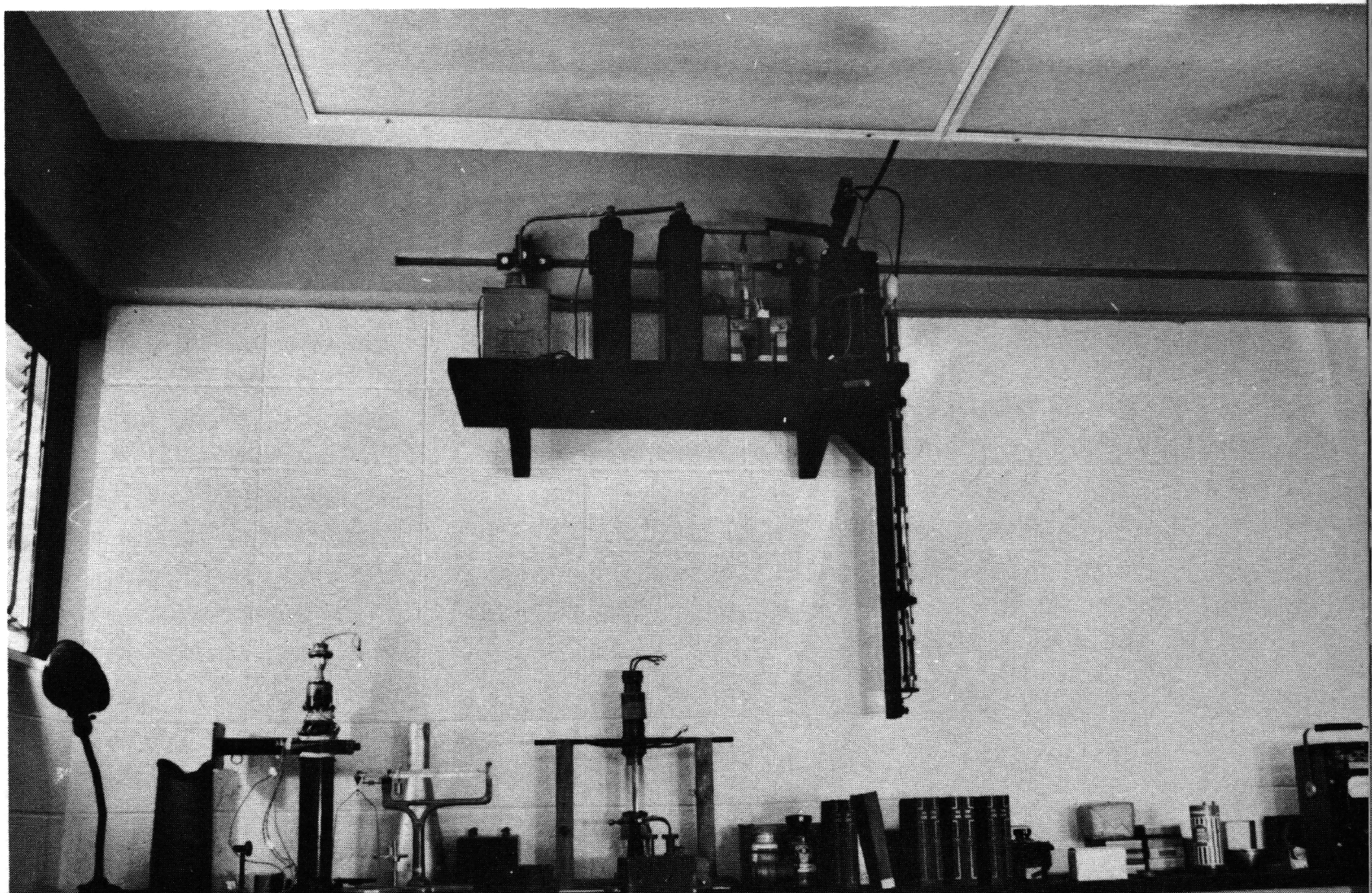


Figure 29. Galvanometer room off the Electrical Measurements Laboratory at Drexel Institute of Technology.

Figure 30. High voltage supply permanently mounted near ceiling in the Laboratory of the Seminar in Modern Physics at Swarthmore.



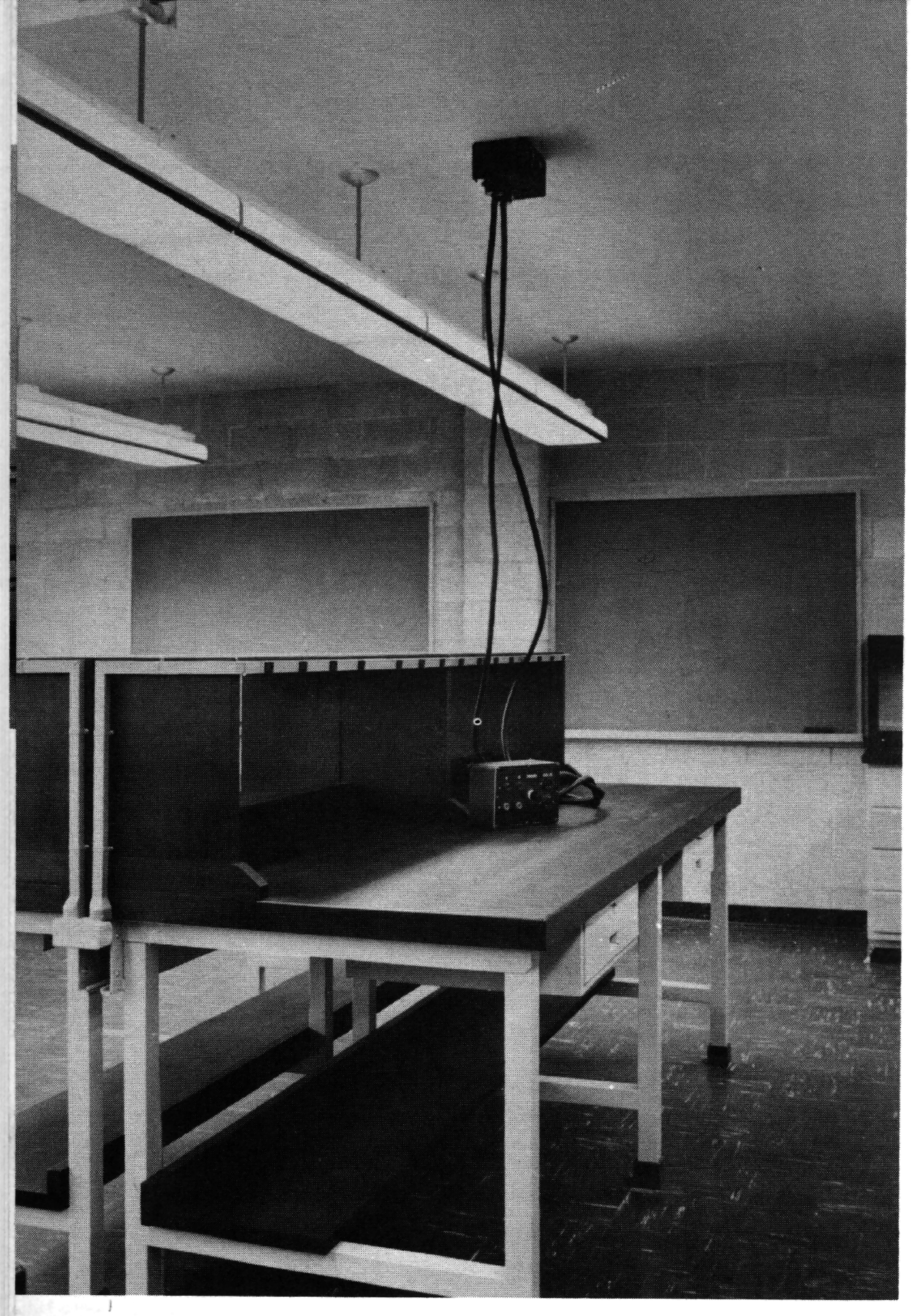


Figure 31. View in Electronics Laboratory at the University of Connecticut showing flexible cables which bring ac and dc power down from ceiling.

Services are sometimes provided by service islands which are permanently installed in the middle of the laboratory. For example, all advanced laboratories at the University of Georgia have service islands similar to those in the Optics Laboratory shown in Figure 27. However, where tables are used in the middle of the room, electric services are more often provided by outlets in the floor—outlets which are installed either in turrets or flush with the floor and provided with cover plates. Electric power is brought to work stations in the middle of the room in the laboratories at the University of Connecticut as shown for the Electronics Laboratory in Figure 31. Both ac and dc voltages are obtained from the box in the ceiling by means of a flexible cable and "twist-lock" plug, and multiple outlets are provided in the box on the table. The cord is sufficiently long so that this box can be moved to any point on the table.

Probably the greatest number of complaints with respect to utilities is an insufficient number of ac outlets. Continuous plug-in strips (similar to Plugmold) are widely used to supplement convenience outlets, particularly in laboratories which use considerable electronic equipment. Where such strips are used at wall benches, they are usually mounted on the wall about a foot above the surface of the bench so that power cords will be out of the way. However, for the sake of greater convenience some prefer that the strips be mounted on the side of the bench just beneath its top. Strips are frequently mounted in this fashion on tables even if they are movable, in which case a flexible cable is used to bring power to the strip.

Both ac convenience outlets and plug-in strips should be of the type that will take the plugs which have a grounded pin in addition to the two terminals for power. Such plugs are standard on the line cords that are now supplied with many instruments. Furthermore, when one side of the power line is grounded, as is usually the case, it is desirable to have that side consistently connected to the same terminal of each receptacle throughout the building, say to the wider of the two terminals.

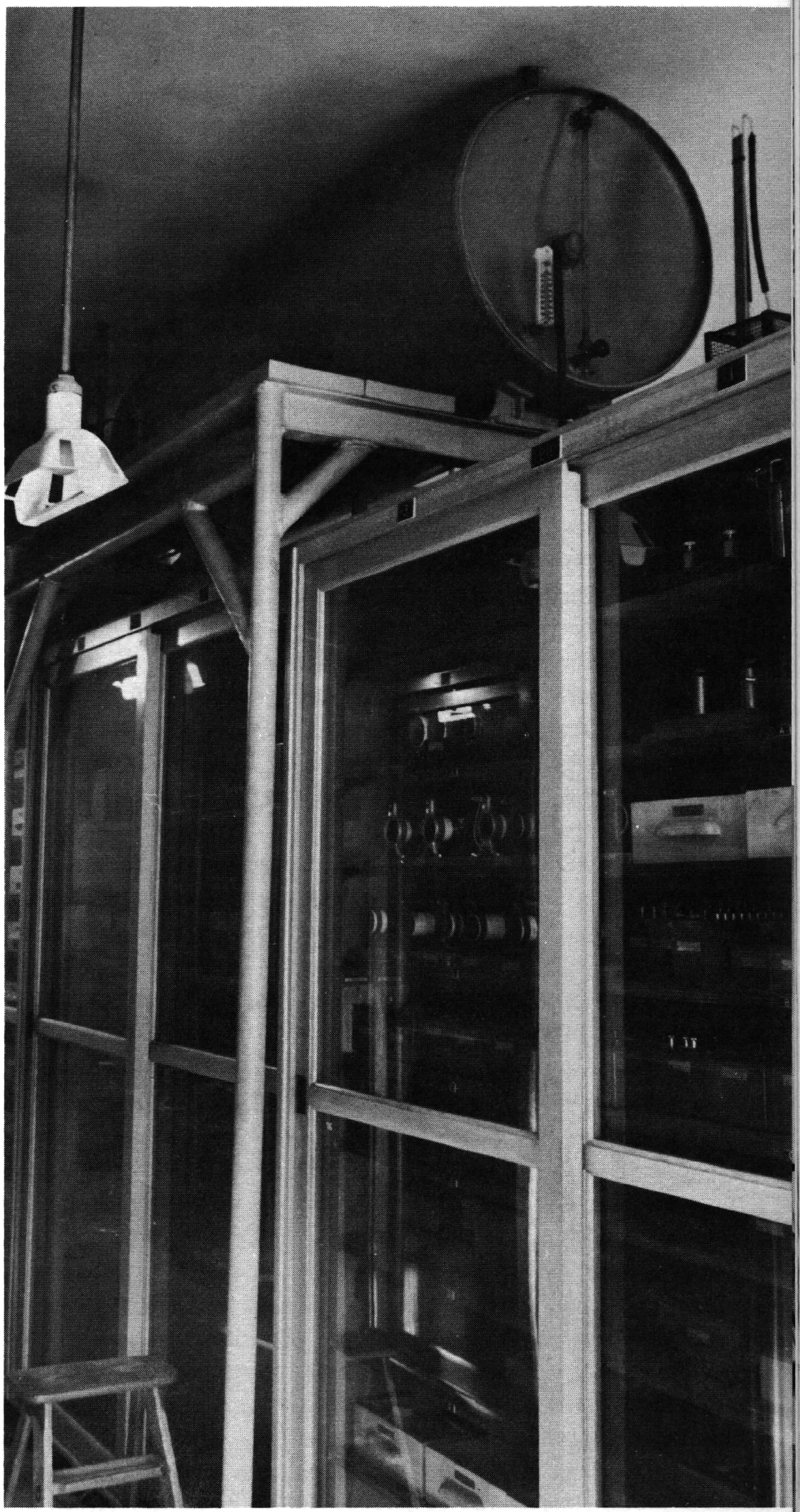
In those laboratories where a central power distribution system and a central battery bank are available, free lines are usually run to the advanced laboratories as well as to other areas in the building. (See Chapter 3 for a description of the system installed at Pomona.) Stations which are supplied with free lines should be provided with two pairs of lines for increased versatility. Among other things, this makes it possible to bring 3-phase ac to the station from the central distribution board, thereby eliminating the necessity for installing separate 3-phase lines. Since many advanced experiments cannot tolerate the voltage fluctuations which result from multiple use of a common source of power, supplemental local batteries and rectifiers are widely used to supply dc power for advanced laboratories even when free lines are available. Because of their limited need for free lines in the advanced laboratory, the staff at Illinois Institute of Technology decided to confine the service provided by the distribution system installed in their new building to the elementary laboratory and the lecture room; free lines were not even extended to the Modern Physics Laboratory next door to the Elementary Laboratory (Figure 10). Direct current power is also distributed throughout most laboratories from a central 120-volt dc generator when available.

Where stopcocks for gas and air are required they should be installed so as to be as much out of the way as possible, especially in areas where they are infrequently used. Stopcocks can be mounted under the overhanging tops of benches, providing the overhang is sufficient to protect the cock from accidentally being turned on.

Water at constant pressure for constant flow experiments can be obtained from an overhead tank which is fitted with an overflow pipe and into which tap water flows. Room temperature water can also be obtained from an overhead tank. Figure 32 shows such a tank mounted on top of the apparatus storage cases in the advanced laboratories at Oberlin. The tank is filled with tap water a few days before it is needed for an experiment.

Services other than those mentioned are usually supplied on a unit basis instead of being permanently installed in the building. For example, oxygen is supplied by portable tanks, distilled water is brought in as needed, and vacuum is provided by individual vacuum pumps rather than by a central vacuum system.

Figure 32. Storage tank for room temperature water mounted above cabinets in the Advanced Physics Laboratories at Oberlin College.



8. Research Laboratories

INTRODUCTION

Research laboratories in colleges and universities must be more versatile than teaching laboratories. Research interests are continually changing as new problems arise and new students enroll. New problems require different equipment which in turn requires a different arrangement of furniture and frequently a different set of utilities. Research laboratories cannot be laid out in detail in the absence of a specific research problem. The neat array of laboratory tables useful in certain teaching laboratories serves little purpose in a research laboratory and indeed may get in the way of effective work. Space is the principal requirement of research—space plus easy access to the utilities that may be required. This chapter will concern itself principally with "universal laboratories"—physics laboratories that are designed with no special research problem in mind.

GENERAL CONSIDERATIONS

Space Needs

The method of carrying on research in our colleges and universities has changed. A few decades ago research was a one-man proposition and buildings were accordingly designed to provide many small one-man research laboratories each about the size of an office. Today most research is carried out by teams—several persons working together on different aspects of the same problem, or working individually but requiring a common major research facility and hence, a larger room.

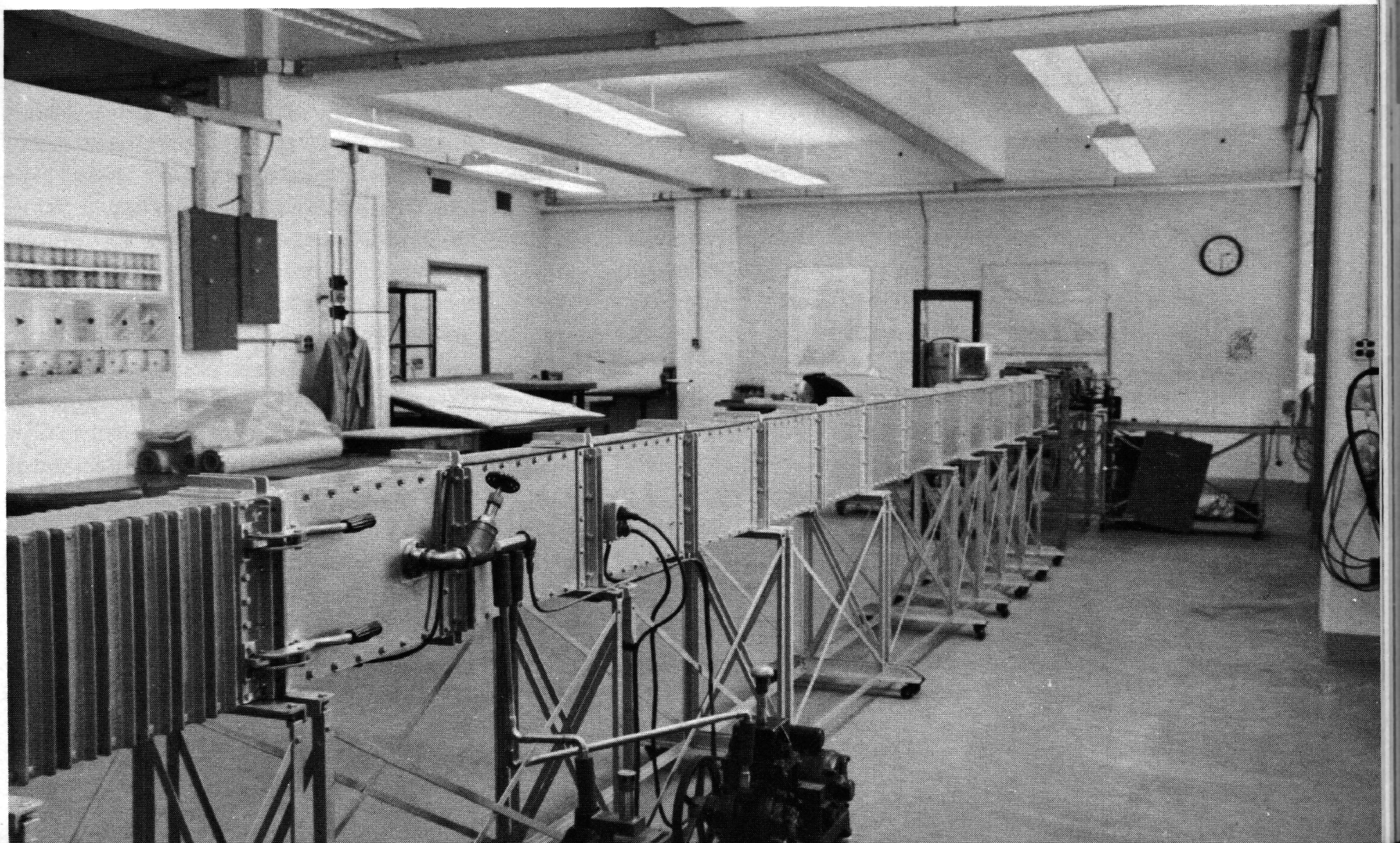
In a survey of 10 universities with new physics research facilities, only one indicated that more than 10% of their research is carried on in single-person laboratories. At California Institute of Technology, 90% of the research revolves around a number of common major facilities. At Ohio State University this figure is only 20%, but the remaining 80% is carried on in multiple-occupancy laboratories. Large rooms are more flexible than small rooms and furthermore, are more economical of space—less floor area is required per person. The elaborate equipment required for many of today's research projects can be more effectively laid out in a large room. The high cost of such equipment also requires that several persons share its use wherever possible. Some persons have also expressed the belief that students working in the same room can "interact favorably and profitably" even though they have different research problems. Finally, large laboratory rooms permit a greater fluctuation in student population.

Where single-person laboratories are provided, they range in area from about 150 to 300 square feet. By reviewing the floor plans of the buildings presented in Chap. 4 one will observe that most of the rooms set aside as research laboratories have at least double this area, and that the rooms vary in size, usually being integral multiples of the building module. Large rooms are frequently needed simply because of the size of the equipment required for a given project; witness the room required to house the shock tube in the Gordon McKay Laboratory at Harvard University (Figure 1).

Location

The decision as to where the research laboratories should be located in a building depends on a number of factors such as (1) the efficiency with which the required mechanical and electrical services can be supplied, (2) floor loading required, (3) freedom from vibration, (4) ease of installing equipment that is either bulky or heavy, (5) ease of access to materials and auxiliary services, and in a building which involves both teaching and research (6) effect of student traffic. It is impossible to satisfy all these requirements for every research room. Research which requires heavy equipment must be confined to floors which have an adequate load rating. A two-ton magnet cannot be mounted on a floor rated at 100 pounds per square foot without providing a base which spreads the load. Because of floor loading requirements and the difficulty of transporting heavy equipment to upper floors, research requiring such equipment is usually confined to the basement (or to the sub-basement) where the concrete floor is poured directly on earth. The ground floor is also best for experiments which require freedom from vibration, though massive piers set deep in the ground are seldom being provided for this purpose in the physics buildings currently being built, as noted in Chapter 3.

Figure 1. Shock tube apparatus in the Gordon McKay Laboratory at Harvard requires a large research room.



So that the electrical and mechanical services required for research can be distributed most effectively and thus most economically, research rooms should be grouped together as far as possible and not scattered throughout the building. Grouping of research rooms has the additional advantage of placing persons with similar activities near each other. The section on Electrical and Mechanical Services in Chapter 3 describes various methods of distributing services throughout a laboratory building. It may be desirable to confine most research activities to the basement and sub-basement where the services required are then run horizontally as at Catholic University of America (Chapter 4, Figure 2); or, to a multi-story research wing or separate research building where the services can be distributed efficiently through vertical risers as in the McKay Laboratory at Harvard (Chapter 4, Figure 5). The extent and type of research will largely determine the pattern at each institution.

Lighting

The general illumination level in research laboratories should be at least 50 foot candles, with increased localized illumination provided by supplementary lamps as needed. Since fluorescent lamps yield more light and less heat per watt than incandescent lamps, the former should be used wherever possible. Methods of minimizing interference due to high frequency radiation from fluorescent lamps are described in a subsequent paragraph. A considerable amount of heat is already released in research laboratories today by electronic equipment and other apparatus that dissipates electric power. Thus, fluorescent lamps are indicated not only for the sake of economy but also to keep down the total amount of heat released in the laboratory during those seasons of the year when additional heat is detrimental to human comfort and places just that much additional load on any air conditioning equipment that may be required.

Large windows on all but the north side of a building are also responsible for too much undesirable heat during certain seasons of the year. Windows need not be large in laboratory rooms which are adequately ventilated and properly lighted. In fact, the complete absence of windows can be an advantage by providing additional wall space which is always at a premium for mounting apparatus or against which benches and cabinets can be placed. If windows are required for certain architectural reasons, they should preferably be small—with sills at least 7 feet above the floor to preserve as much usable wall area as possible. We have visited several physics buildings which have extensive wall areas in glass only to find large areas of the glass covered with aluminum foil to exclude either the heat or the glare of unwanted light. This emphasizes the desire that most research workers have for a minimum of glass. Lamps should be mounted close to the ceiling to provide as much clearance for movement of apparatus as possible.

Structural Considerations

WALLS. Since walls in research areas are extensively used for supporting apparatus, the principal requirement of them is that they be sturdy. Four-inch masonry block walls are widely used and are sufficiently substantial for most loads they are called upon to carry. That such walls are not good acoustical barriers is not usually a significant factor in research areas. (Their transmission of sound can be reduced by closing the pores in the masonry blocks with either heavy paint or plaster on one side.) As explained in Chapter 3, there is less need for expensive movable walls between research rooms in educational institutions than in industrial laboratories. Non-load bearing masonry walls can be moved without too much difficulty, especially if the conduit and pipes for services are attached to the surface of the wall rather than embedded in it.

The effective manner in which the wall of a research laboratory can be used for sup-

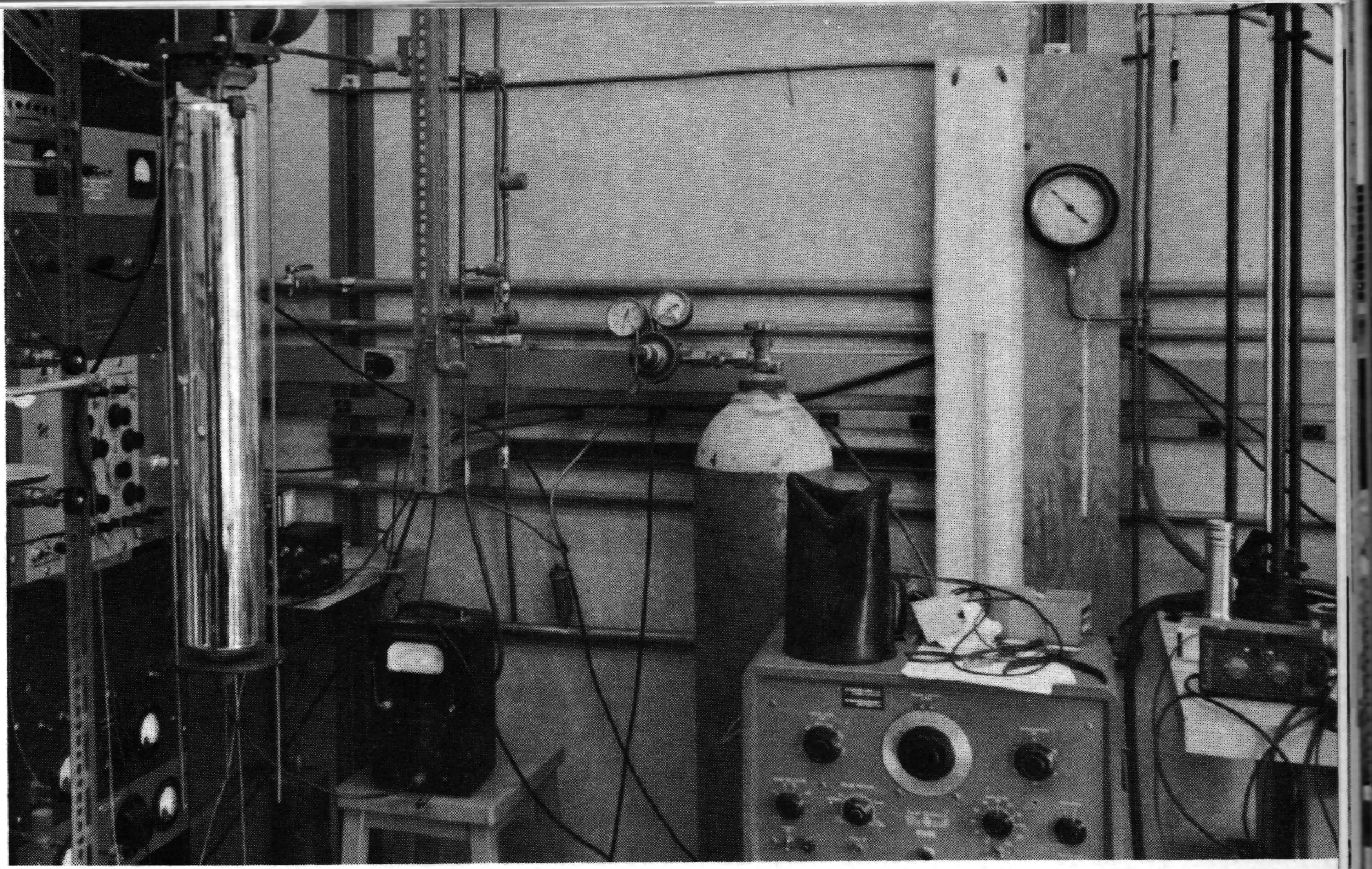


Figure 2. Metal channels in the wall support experimental apparatus and utilities in research room in the Gibbs Research Laboratory at Yale University.

porting apparatus is shown by the photographs taken in a laboratory in the Josiah Willard Gibbs Research Laboratory at Yale University (Figure 2). The wall consists of a rigid cement-asbestos panel (Cemesto) supported in a vertical frame of patented steel channel (Unistrut). The Unistrut channels are flush with the surface of the Cemesto as described in Chapter 3. Note how readily pipes, conduit and surface metal raceways (for electric power), and wooden boards can be supported from the channels in the wall. Two additional Unistrut channels are surface mounted between two of the vertical channels to provide an extended base frame for supporting apparatus. Note also how angle iron punched with holes and slots (Dexion) is used for supporting additional apparatus. Such angle (manufactured by Acme Steel Company, 454 Alwood Road, Clifton, N. J., in both steel and aluminum and in a range of sizes) is widely used for this purpose because of its versatility of assembly.

Metal channels for supporting apparatus are more often surface mounted rather than set into the wall. This is clearly the simplest procedure for block and tile masonry walls. Some prefer to run the channels horizontally, in which case two channels are used—one about 3 feet off the floor and the other about 7 feet. Surface mounting is used in the top floor of the Gibbs Laboratory. This floor was added after the rest of the building had been completed and block walls were used to separate research rooms instead of the panel construction in the lower floors.

Since it is frequently desirable to run cables from one room to another, holes sealed with removable plugs should be available in the walls between adjacent laboratories (and between laboratories and corridor) for this purpose. They are usually located near the ceiling. Service riser space can be used for cables run between floors. Alternatively, holes with removable plugs can be provided at intervals in the floor.

Where it is desirable to subdivide a large room without building permanent walls, benches with tall backs (for tools and shelves) and apparatus cases and shelves serve well as space dividers. Continuous strip wire raceway for electric power can be mounted along the back of the bench or along the front beneath its overhanging top, and connection can be made to a source of power at the wall by flexible cable.

CEILINGS. Ceilings in research areas are usually exposed concrete slab. They are frequently called upon to support apparatus and this can be accomplished by a variety of devices inserted in the concrete, preferably at the time the ceiling is poured. Metal channels (such as Unistrut) can be embedded in the side of the concrete beams. Holes spaced at desired intervals and filled with metal sleeves can traverse the beams. Metal inserts of various kinds can be inserted flush with the ceiling—metal inserts that are threaded to take bolts, and inserts with keyhole shaped slots for taking the heads of bolts. Bolts are also sometimes inserted with their threaded ends protruding. The usefulness of metal channels embedded in the ceiling for supporting metal racks in one of the research laboratories at the University of Maryland is shown in Figure 3. A variety of items can be stored out of the way on such racks.

Ceilings have caused trouble by releasing dust in some laboratories. At one laboratory where the ceiling "consists of cinder blocks which are held in place by concrete poured over them" the staff reports that "a fine shower of dust continues to be let down (even) after many years of use. Mechanical and optical equipment must be covered at all times." One should clearly specify that the type of ceiling to be installed shall not have this characteristic.

Floors. The surface of the floor in most research laboratories is simply smoothly trowelled concrete, though some floors are covered with asbestos tile or occasionally with vinyl. Floor loading in research areas is usually at least 75 pounds per square foot. Apparatus requiring more support is either confined to the basement, or it is mounted on a frame which spreads the load over a larger area.

A floor drain should be provided in all laboratories where water may be used. At one laboratory where such drains were not provided, the shop foreman reports that the shop is flooded due to overflow from drains which get stopped in some laboratory above him "at least one night a month." At another laboratory the chance of overflow reaching floors below is minimized by short

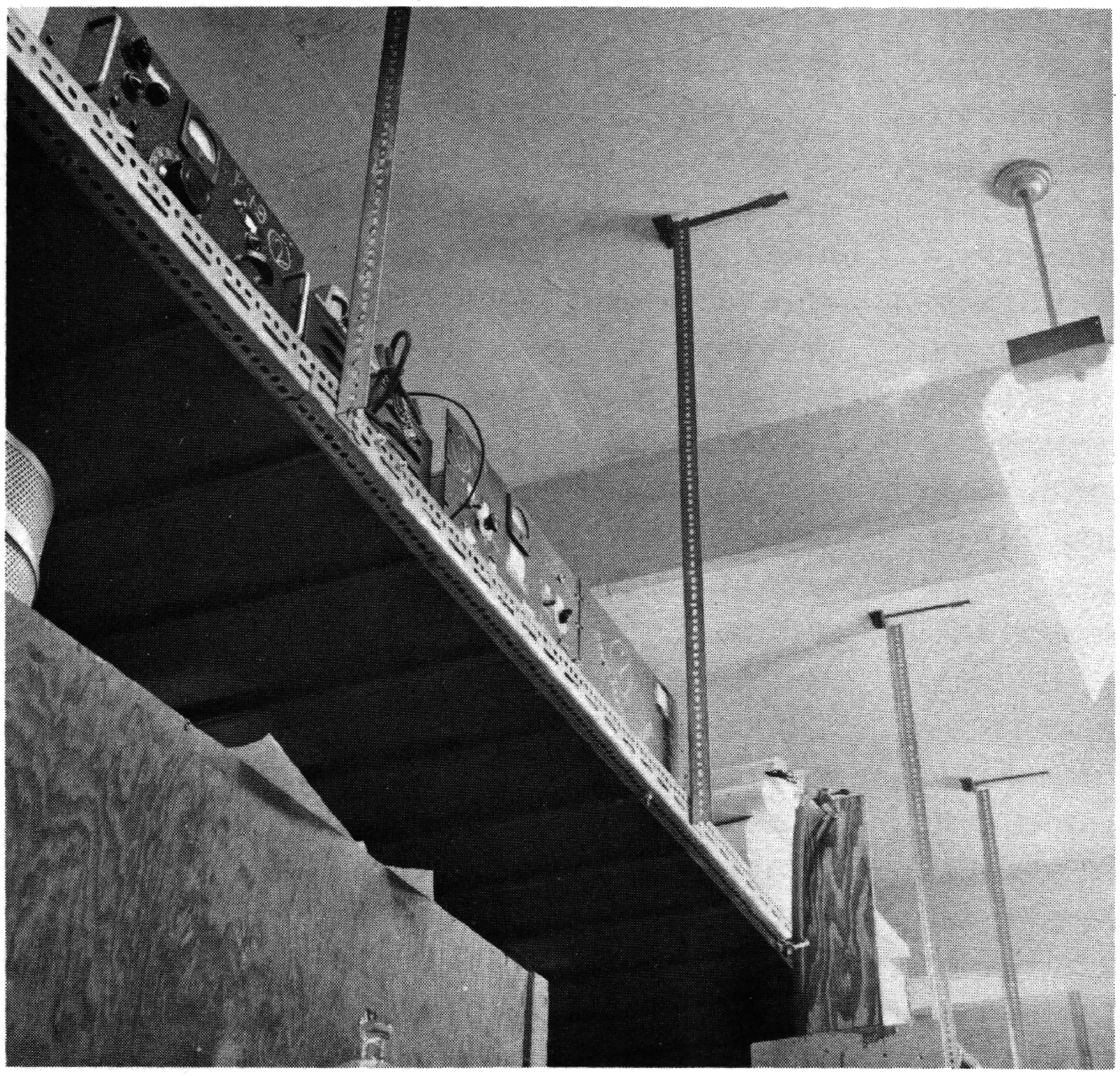


Figure 3. Metal channels in the ceiling support racks for storing apparatus in research laboratory at the University of Maryland.

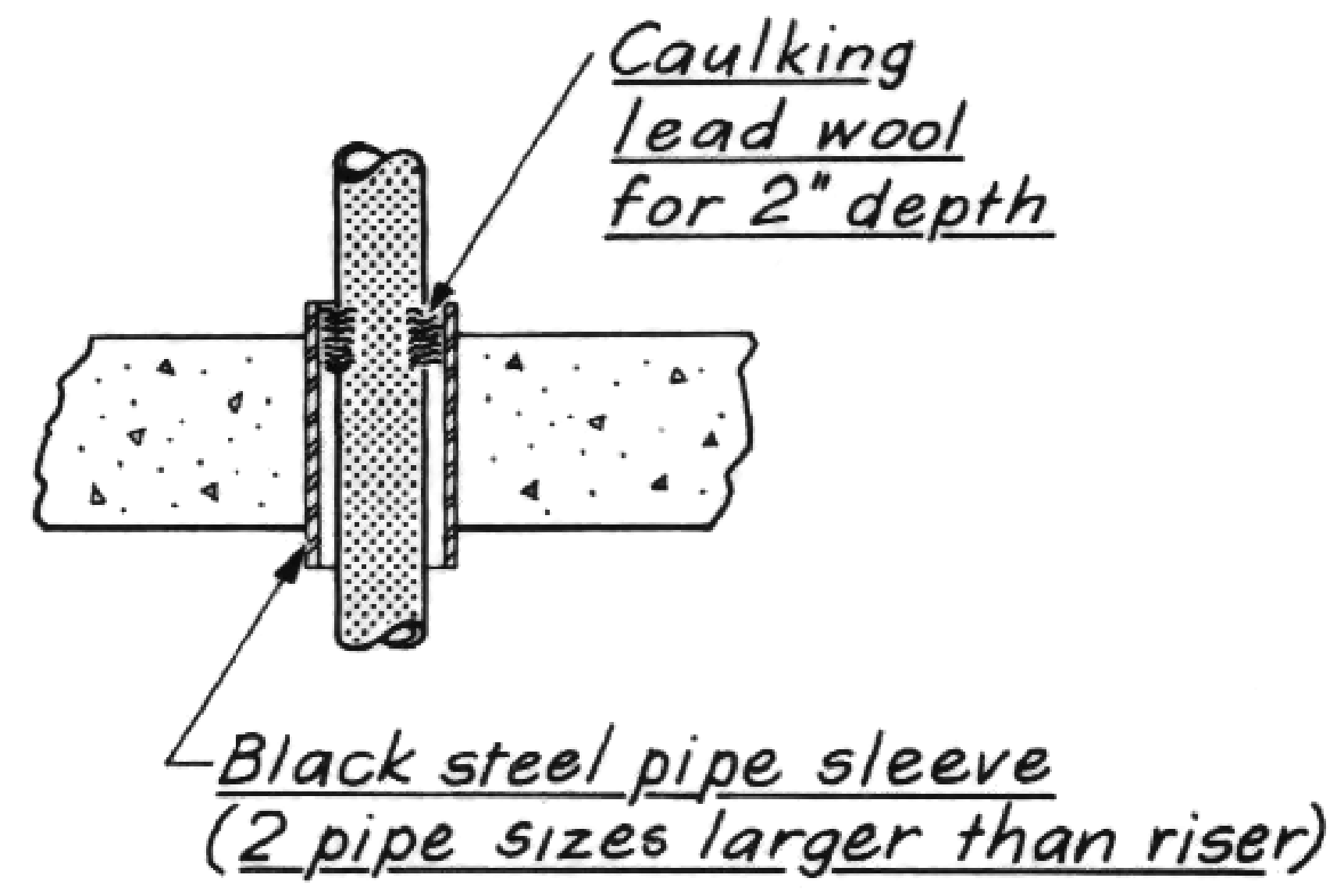


Figure 4. Cross-section drawing of pipe sleeve in concrete floor surrounding riser pipe which keeps overflow from floor below.

metal sleeves which surround all riser pipes as shown in Figure 4. The steel sleeves (about two pipe sizes larger than the riser pipe) are positioned at the time the concrete slab floor is poured, and are of such a length that when flush with the bottom of the slab they project about 1 inch above the surface of the floor. After the riser pipe has been installed the space between the two pipes is caulked at the top with lead wool.

An opening in the floor is often a convenience in a research laboratory. Figure 5 shows an elongated pit along one side of the cryogenics laboratory in the new physics building at the University of Illinois. The pit enables one to lower nitrogen Dewar flasks and other apparatus beneath the helium Dewar flasks suspended from the overhead vacuum system. A magnet on wheels can be rolled along the rails which straddle the pit.

Doors. Doors in research laboratories should be wide enough to admit the largest pieces of equipment likely to be required. They should be at least 3 feet and preferably 3½ feet in width. Double doors are frequently installed—sometimes with one of the doors narrower than the other and kept closed except when the wider opening is required. (A removable center post may or may not be provided.) Some laboratories have a removable panel at one side of the door so that a greater width can be obtained when the panel and door jamb are removed. Similarly, removable panels are sometimes installed above doors to provide openings of greater height when needed.

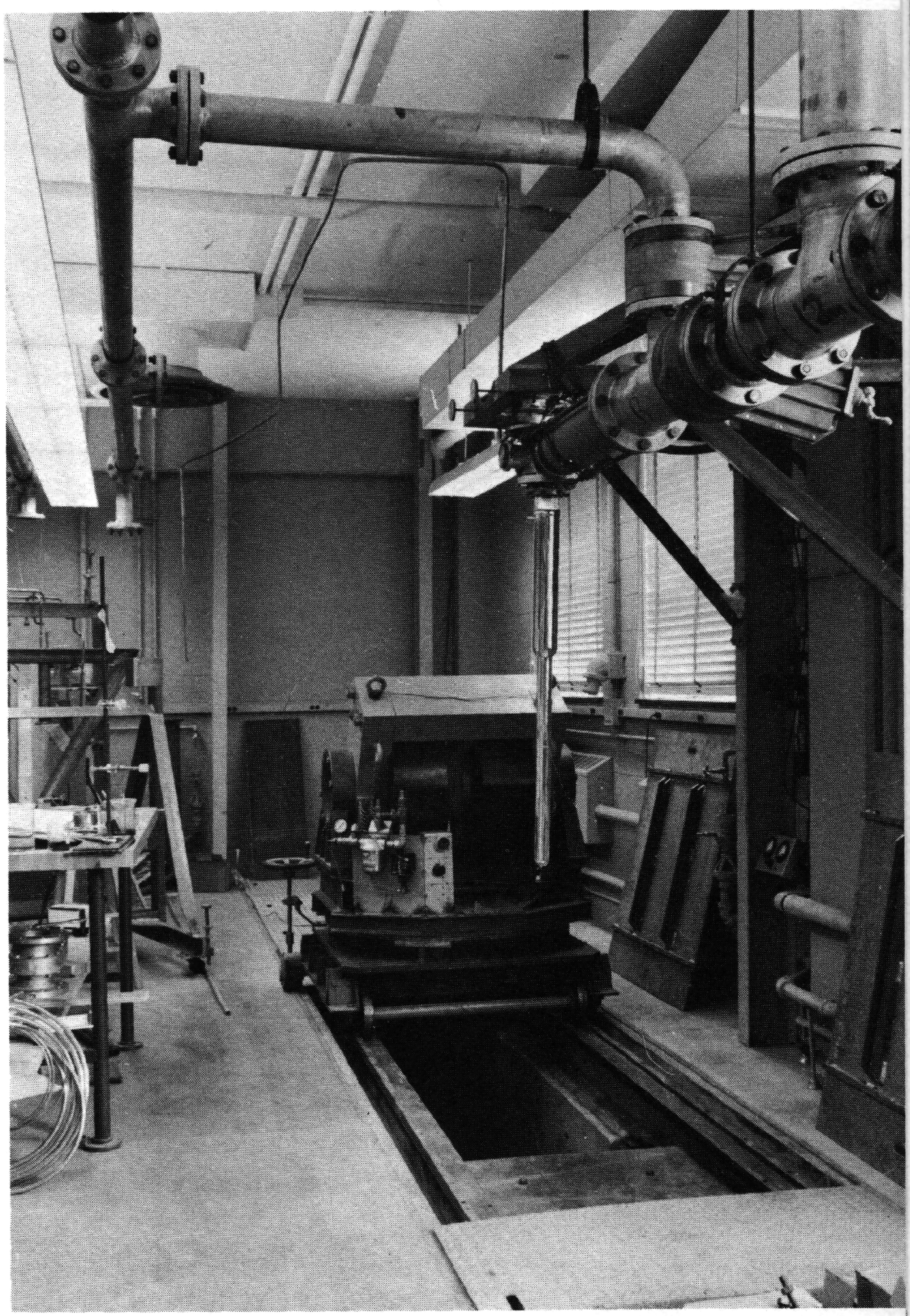


Figure 5. An elongated pit runs along one side of the cryogenics laboratory at the University of Illinois.

Raised thresholds should not be installed in the doorways in physics buildings—especially in those areas such as research where it is frequently necessary to move apparatus into and out of the room.

Local codes sometimes require secondary doors or other means of egress from certain types of laboratories in case of emergency. This is highly recommended for rooms where hazardous operations may be under way.

FACILITIES

Laboratory Furniture

The furniture required in research laboratories varies with the work under way. Work benches with durable tops (see Chapter 3 for a list of top materials), open shelves and cases with shelves and drawers for storing instruments and supplies, desks for work requiring writing and study are all required in varying degree by each laboratory. However, there is no standard pattern in which such furniture is arrayed. Furniture in a research laboratory is seldom fixed in position, at least until the needs of the research underway so require it. This does not apply to fixed service islands that occasionally are desired, either along a side wall or projecting from the corridor wall as described in a subsequent paragraph. (See Figures 9 and 10).

Most researchers prefer wooden tables and benches or at least wooden tops. All-steel benches are avoided because of the shock hazard. A dilemma arises—for greater safety, should benches be grounded, or should they be insulated from ground? However, frames assembled from standard steel pipes frequently serve as bases for tables and benches. The magnetic property of steel requires that it be avoided in some laboratories.

Much of the apparatus for today's experiments is mounted on racks that are constructed as needed using the versatile punched metal angle now available commercially (such as Dexion shown in Figure 2).

Piers

Massive piers for experiments that require freedom from vibration used to be installed in the basements of most physics buildings. Occasionally piers even continued upwards through the basement to accommodate apparatus on the next floor. Each pier stood free of the building and passed through the concrete floor of the basement and to a considerable depth into the ground. Such piers, being immovable, use up valuable space and are frequently in the way. Piers which have their tops flush with the surface of the floor serve equally well, and tables which are used with them can be moved out of the way when not required. Furthermore, various other measures are available for isolating equipment from vibration. Hence, massive piers which extend into the room have seldom been installed in recently constructed physics buildings.

Services

Requirements. The major electrical requirement for a physics research laboratory is a liberal distribution of power at 120 volt single phase ac. Three-phase power is also occasionally desired and is readily available if, as is usually the case today, the main power is provided as 4-wire Y-connected, 120/208 volt, 3-phase ac. When so provided, the several single phase outlets in each laboratory should be on different phases to distribute the load more uniformly. Most laboratories also have direct current available from a central motor-generator—usually 120 volts, though often at plus and minus 120 volts from ground. Some laboratories provide a central distribution system with a central battery bank and free lines running from each laboratory to the central switchboard (see the discussion of central systems in Chapter 3). However, such systems are less useful for providing dc for research laboratories than for teaching laboratories, for in research one cannot countenance the change in voltage that results when other persons plug into the same source. Local batteries or rectifiers provide more satisfactorily the constant uninterrupted voltages that are required for research.

Regulated 60 cycle ac is sometimes made available on separate lines which run to certain laboratories. At Catholic University of America, regulated ac is provided on one line in each research laboratory by a saturable reactor permanently mounted in each room. On the other hand, most laboratories rely on portable regulators which can be used where required. It should be noted that saturable reactors are frequency sensitive, and can therefore be relied upon only if the frequency is constant. Electronic regulators are required where the frequency is not constant.

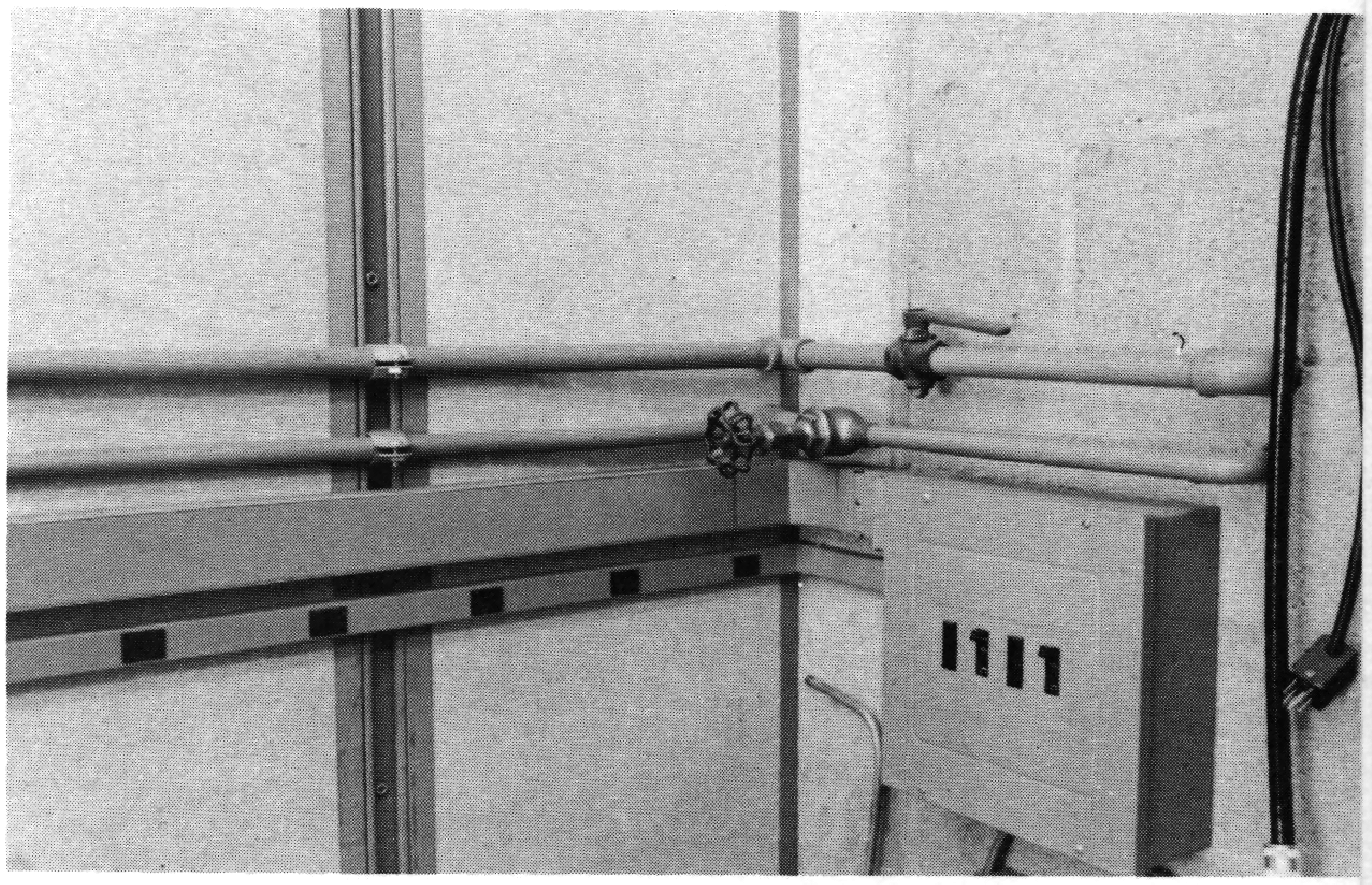
An electrical ground that is separate from the grounded conduit of the electrical system should be provided each laboratory. If a copper plate or rod is to be a satisfactory ground, it must be buried sufficiently deep to be in moist earth at all times. A research project requiring a particularly "quiet ground" must have its own separate lead to ground.

Finally, since it is now possible by means of closed circuit television to show research projects currently under way to large groups of persons, consideration should be given to the advisability of installing the necessary coaxial cables between research laboratories and the physics lecture room and possibly the classrooms. If cables are not installed initially, routes should be left open for their subsequent installation when required.

Running cold water, waste lines, compressed air and gas, are the mechanical services that should be available in all laboratories. Hot water is frequently supplied as well, in which case it is usually continuously circulated so as to be more immediately available at each outlet. Vacuum lines used to be distributed throughout physics buildings, but their installation has largely been discontinued. Since it is difficult to keep such systems free of leaks (and all stopcocks closed), they provide only a rough and uncertain vacuum at best. Local vacuum pumps with local control are required for research. When certain gases such as oxygen are used in a number of rooms it may be desirable to connect the rooms by pipe to a single central source of supply. This diminishes the demurrage on tanks; however, it represents a saving in the long run only if the system is free from leaks.

METHODS OF DISTRIBUTION. Electrical and mechanical services can be brought into research laboratories by various routes, as described in Chapter 3. The usual procedures provide these services at the corridor wall of the laboratory, either at each bay along the corridor or at alternate bays. For instance, in the Gibbs Laboratory at Yale, conduit for ac and dc power, and pipes for gas and compressed air, are brought to successive floors along one side of the pillars which frame the building (at each side of the corridor); and pipes for hot water, cold water and drain are located on the other side of the pillar. (See Chapter 3, Figure 9.) Services are subsequently brought through the corridor wall into research rooms as needed, and the pipes and conduit are run along the surface of the walls or ceiling to the point required. Figure 6 shows the point where air, gas and electric power enter one of the research rooms. Note the cutoff valves in the gas and air lines and the circuit breakers for electric power. Lines for heavy duty ac power as well as free lines for dc from a central battery bank are carried in the flat metal raceway attached to the wall, and low duty service outlets are provided at frequent intervals, by a narrow continuous strip raceway. Had water been required in this area of the room the necessary pipes for hot and

Figure 6. Gas, air and electrical services are surface-mounted for greater flexibility in the Gibbs Laboratory at Yale.



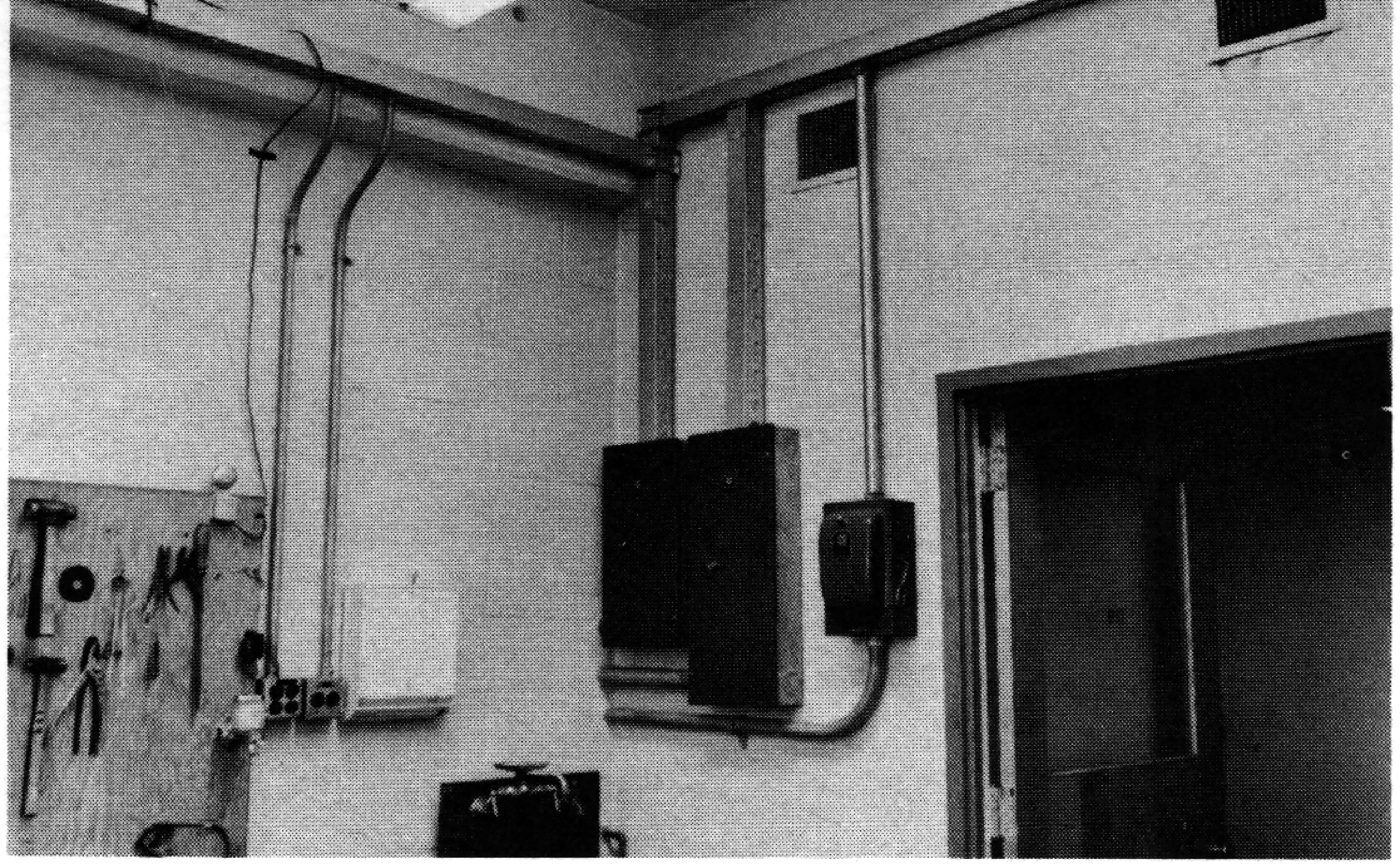


Figure 7. Electrical services are distributed through 4-by-4-inch metal duct mounted near the ceiling in research rooms in the McKay Laboratory at Harvard; conduit is brought down where service outlets are required.

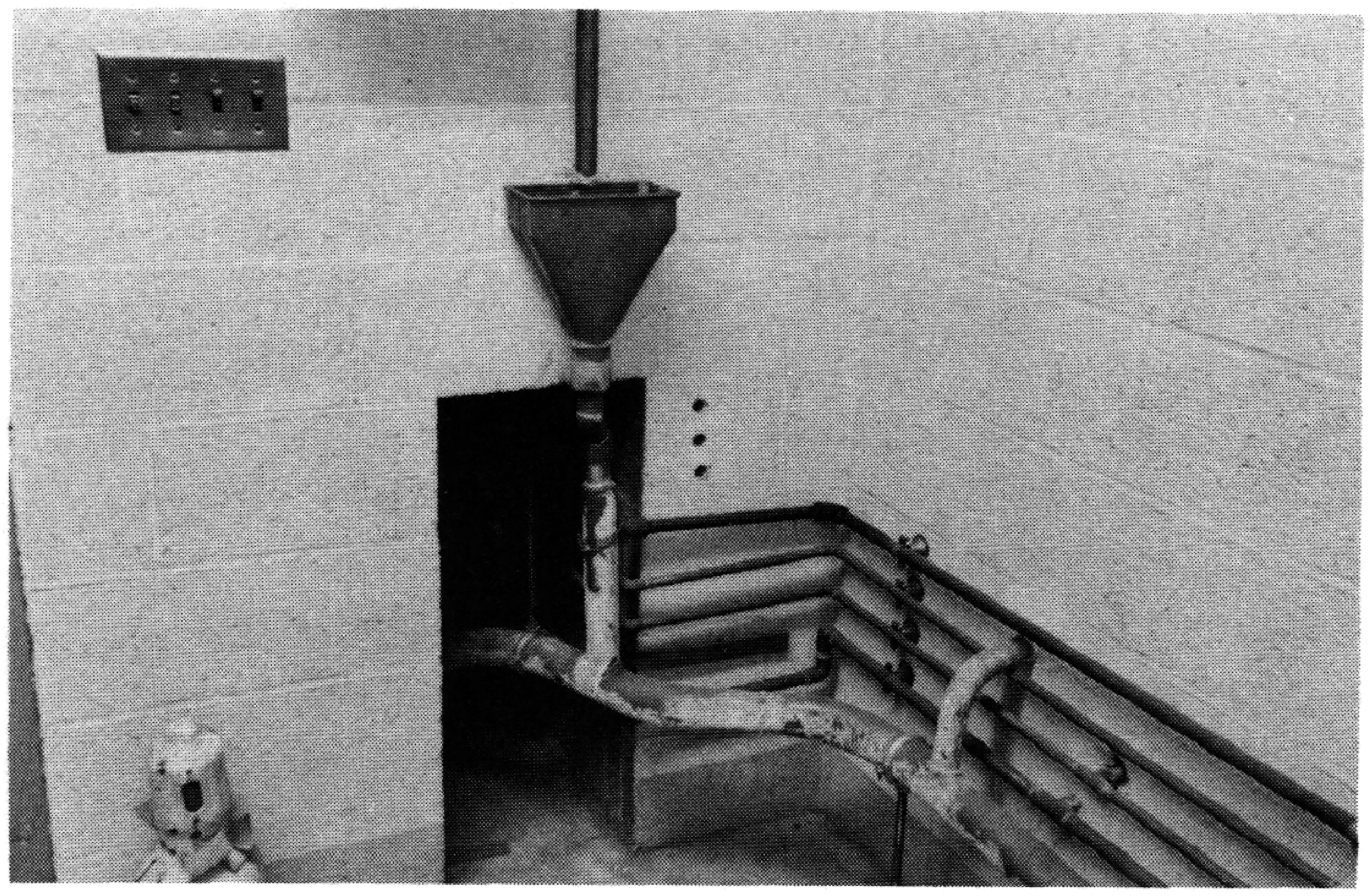


Figure 8. Mechanical services are brought out from vertical risers into research rooms near the floor in the McKay Laboratory at Harvard to stopcocks and sinks as needed.

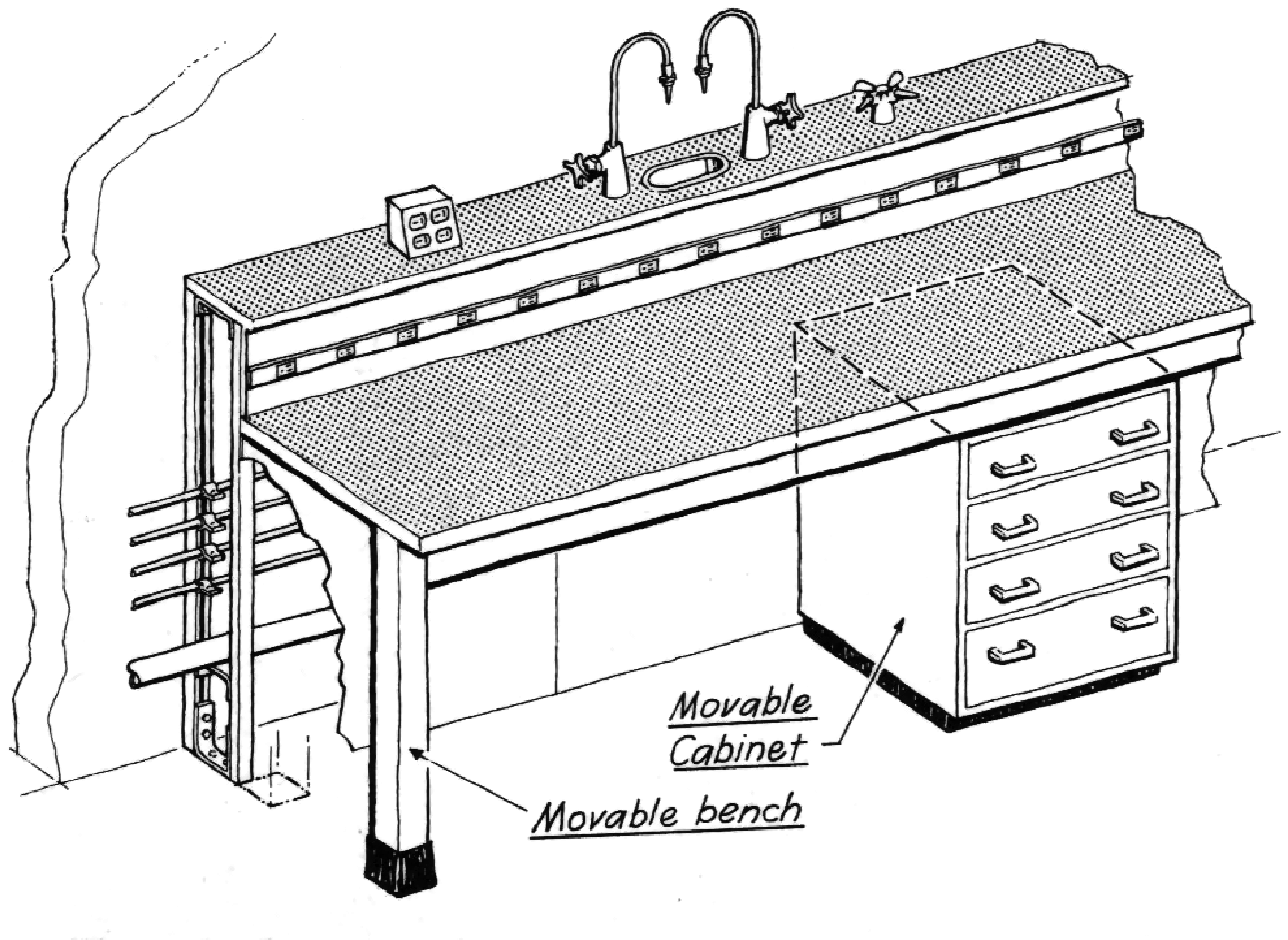


Figure 9. Drawing of service island, installed along wall of research laboratory, and movable bench and cabinet.

cold water and drain would have been brought through the wall from the adjacent laboratory.

A somewhat similar method of distributing services is used in the Gordon McKay Laboratory at Harvard University (Chapter 4, Figure 5). All mechanical services—gas, hot and cold water and drain, and electrical services are brought to successive floors through separately enclosed risers located at alternate building modules (at 24-foot intervals), as described in Chapter 3. Electric power is brought into each laboratory and distributed through 4-by-4-inch metal duct attached to the side walls near the ceiling, and from there it is dropped down through conduits to outlets as required (Figure 7). One side of the metal duct is removable for ease in making changes. The mechanical services required in this room must be brought through the wall from the adjoining laboratory room where they enter the room from the mechanical risers as shown in Figure 8.

Conduit, wireways and boxes for the distribution of electric power should be located so they will take up as little valuable wall space as possible. We have been in laboratories where the staff complained because boxes mounted on the side walls get in the way of effective use of space. Since it is impossible to determine the points where power will be required at the time a building is built, it might be well to postpone the installation of outlets for electric power along the side walls of research rooms until needs are determined, and initially install only the main distribution box at the point where power enters the room. To be sure, conduits for a judicious sprinkling of convenience outlets could be installed in the permanent walls when the building is built—at the same time that conduit for lighting goes in.

Where it is desirable to have a bench along one wall of a research laboratory, the desired services can be provided by a service island as shown in Figure 9. Water at cup sinks, stopcocks for compressed air and gas, and boxes containing outlets for ac and dc power

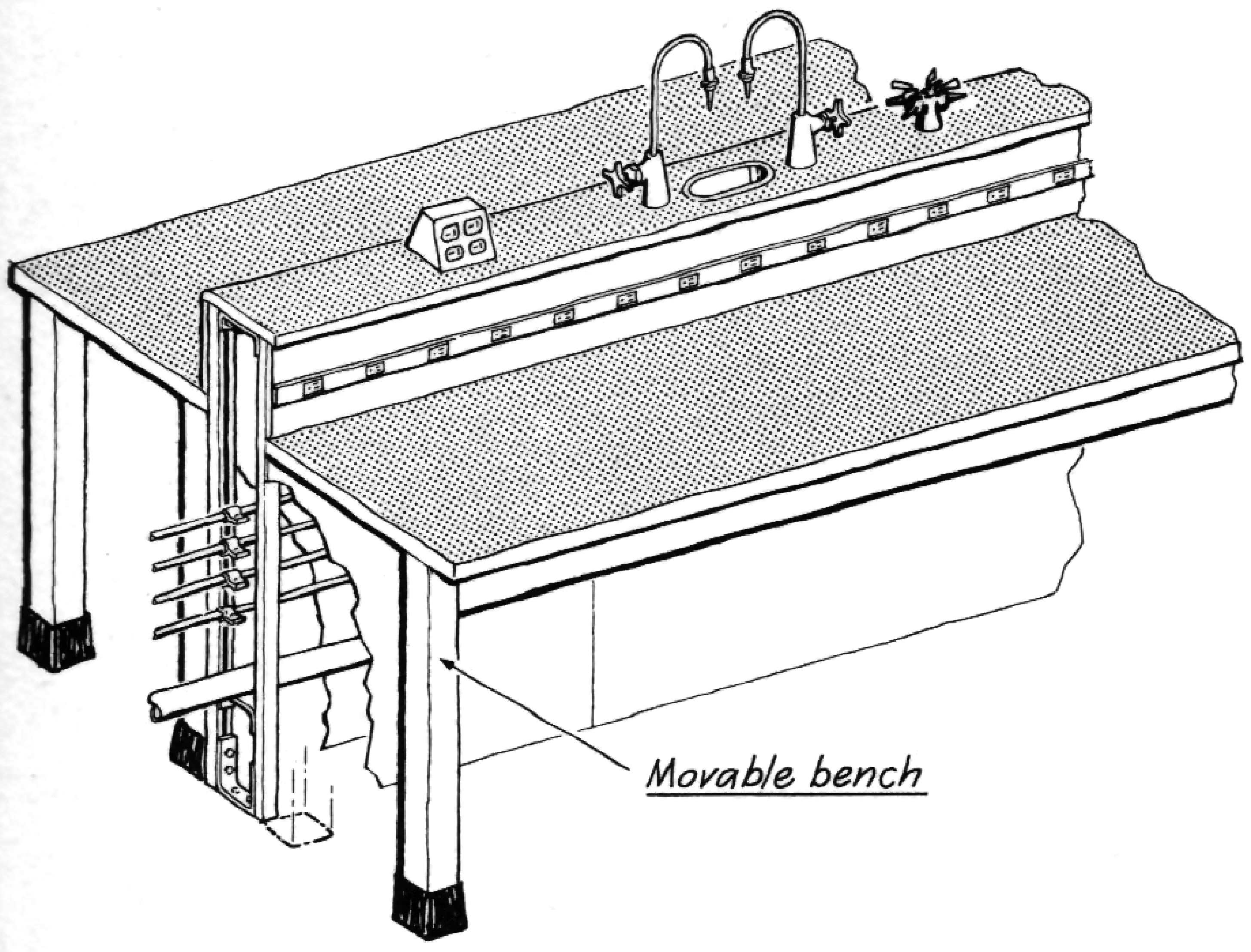


Figure 10. Drawing of service island designed to serve two movable benches placed perpendicular to corridor wall.

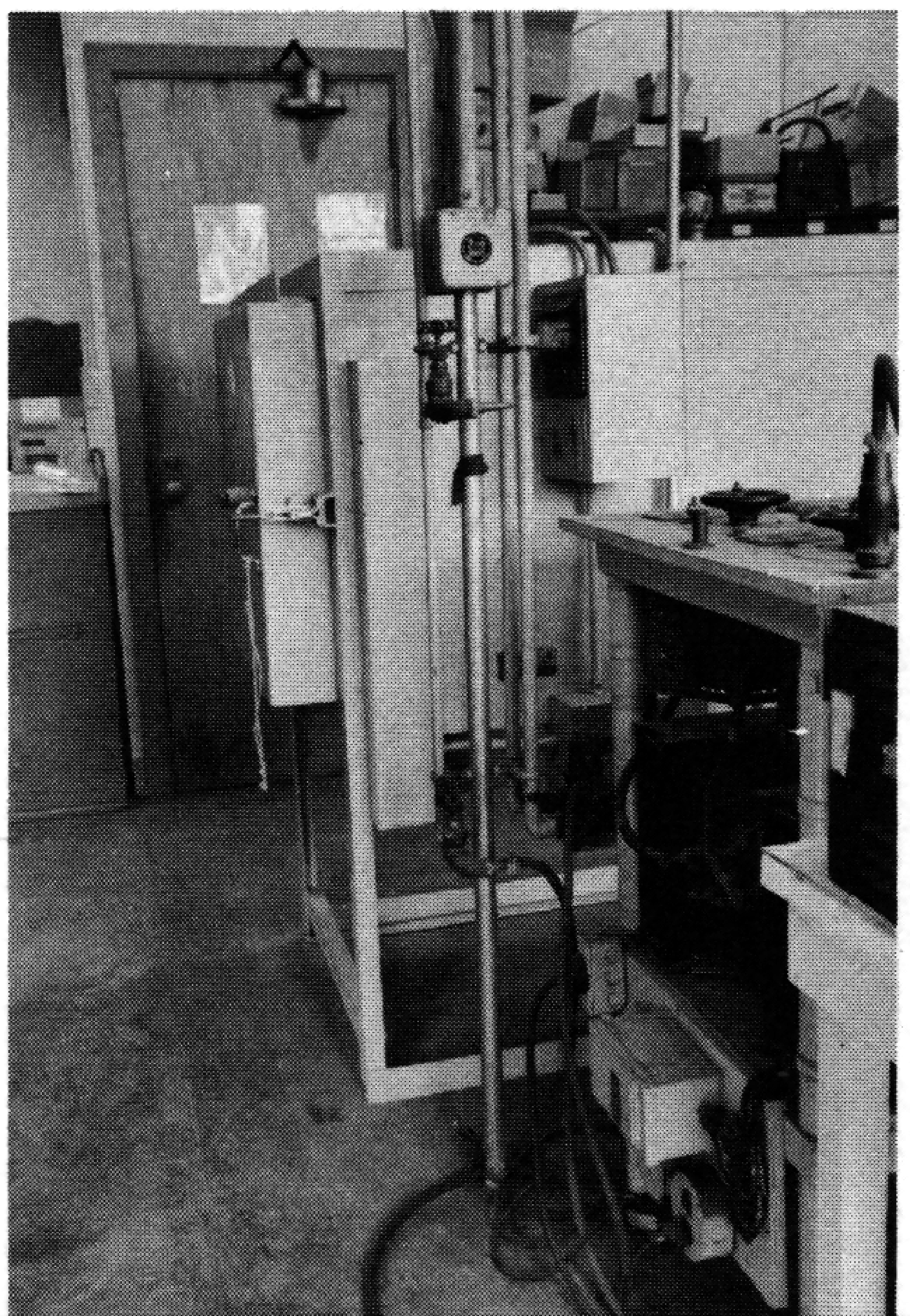
are mounted at intervals on the top of the island, usually about 8 inches above the top of the bench. A continuous strip for ac is also frequently mounted on the face of the service island. Pipe and conduit for the services are carried on a rack which is attached to the wall. The front panel is in sections so that it can easily be removed as needed to make changes or to get at cutoff valves which may be located within. The work bench can readily be moved since plumbing and electric services are not attached to it.

A similar service island is sometimes installed as shown in Figure 10 to provide services for two work benches in the middle of a laboratory. The unit is perpendicular to the corridor wall and extends only part way into the room. It is located at such a point that the required services can readily be fed into it.

Various methods have been used to get electrical and mechanical services to equipment in the middle of a research laboratory. Service islands have sometimes been installed in the middle of laboratory rooms but because of their inflexibility this is seldom done today—at least in research areas where precise needs cannot be predicted. Some laboratories provide outlets for electrical power in the floor—located where the power may be required, and covered with metal plates when not in use. Both conduit and boxes are embedded in the concrete floor, the boxes having been positioned at desired locations at the time the concrete was poured. Other laboratories leave a shallow channel or trench in the floor—a channel which is covered with a metal plate and in which either pipes or conduit can be laid. One laboratory which has trenches reports that "they are not used; they are a source of trouble—avoid them!" Others report that they are "very useful." In any event, if a trench is installed, it should be provided with a drain.

The simplest and most direct method of getting services to apparatus in the middle of a room is to lay the necessary pipes or conduit (or cable) on the floor and protect them with metal or wooden inclined strips. Such a procedure may not be desirable in some locations because of the danger of tripping. It is safer to drape cables and flexible tubing overhead—though perhaps less elegant. A good procedure is to carry whatever conduit and pipe that may be required across the ceiling and drop it at the point where the services are needed. The vertical sections of pipe and conduit can be stabilized by clamping them to a temporary post which is inserted between floor and ceiling. Figure 11 shows how a steel pipe, flanged at floor and ceiling, is used in this fashion in one of the rooms of the McKay Laboratory.

Figure 11. A steel pipe serves as a pillar for attaching service outlets brought down from the ceiling in center of research room in the McKay Laboratory at Harvard.



Inverted service islands, suspended from the ceiling, have been installed in some of the research laboratories in the wing recently added to the physics building at the University of Texas (Figure 12). They will be used to supply gas, air and electrical power to points in the middle of the rooms.

Where a number of research rooms along one corridor require heavy power they may be served by bus duct which runs through the rooms near the ceiling, as shown in the photograph of Figure 13, taken in one of the single-person research laboratories in the LeConte Addition to the Physics Building at the University of California in Berkeley. Power is brought out through a heavy duty switch and by way of conduit to the rectifier that provides dc for the magnet which appears on the left in the picture.

CUTOFF VALVES, SWITCHES AND FUSES. Too often the cutoff valves for water, air and gas cannot be easily located. Valves for these services should be provided for each laboratory separately, and they should be conveniently located and clearly labeled. Likewise, circuit breakers and fuses both for convenience outlets and for power for each laboratory should also be conveniently located and clearly labeled. Convenience outlets are usually fused at about 20 amperes; power lines, at up to 100 amperes and sometimes more.

Control of Interference

Radio-frequency interference from fluorescent lamps can adversely affect certain experiments by introducing false signals into sensitive electronic circuits. This interference is due to the high frequency oscillations which are set up each time the current is turned on and off—120 times per second. It arises from two sources: radiation and feedback from the supply line, and direct radiation from the lamps. The adverse effects can be minimized where they are too troublesome. Radiation from the supply line can be reduced by using rapid start lamps together with simple filters which are available commercially at each lamp. Radiation from the lamp can be reduced by shielding at the lamp. Two methods of shielding are available when recessed troffers are used; the troffer can be enclosed with either an electrically coated conducting glass panel (EC

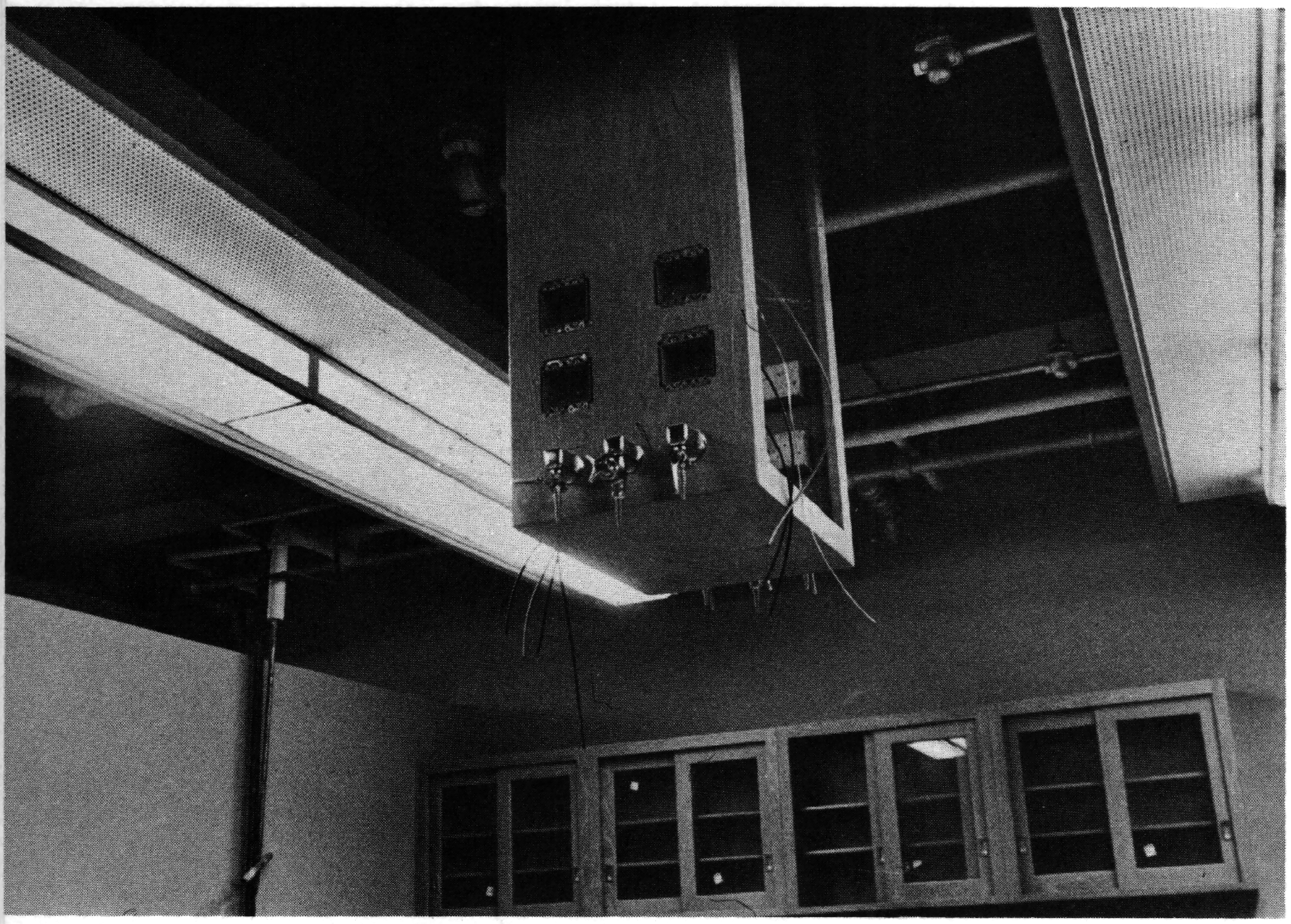


Figure 12. Inverted service island installed in research laboratories in new addition to the Physics Building at the University of Texas.

No. 70 low brightness glass manufactured by the Corning Glass Works) or a metal panel having a small honeycomb structure (such as Honeylite, made by the Hexcel Products Company)—with the panel grounded to the metal troffer in each case. Since incandescent lamps often produce adverse radiation effects near the end of their life, they have no special advantage in this respect over fluorescent lamps which are properly shielded and used with filters. Such precautions are, of course, required for only the most sensitive electronic installations. Decreased distance from the source of disturbance is sometimes all that is required.[1]

Circuit breakers and relays connected with experimental apparatus can produce undesirable signals in the power line and introduce false counts in nearby scalers. Such signals should be by-passed to ground by connecting capacitors to ground from each terminal of the offending switch.

Some new physics buildings have provided one or more rooms which are electrostatically shielded. Copper hardware cloth of fine mesh is embedded in the floor, walls and ceiling. The door must also be specially constructed with the screen through its center, and if there are windows they must also be properly screened. (Roll screens with spring rollers are sometimes used.) All screen sections must be connected together and well grounded. It must be observed that though such a room is also shielded from high frequency radiation it is not shielded from slowly changing magnetic fields. Nearby heavy duty power lines can cause undesirable disturbances. Hence, such rooms should be well removed from ac mains. Furthermore, lights for the room should be recessed in the ceiling and shielded.

The isolation of equipment which is sensitive to vibration has been discussed previously in the section on "Piers." Equipment such as motor generators, pumps and reciprocating mechanisms which are sources of vibration should likewise be isolated by mounting them on properly cushioned supports.

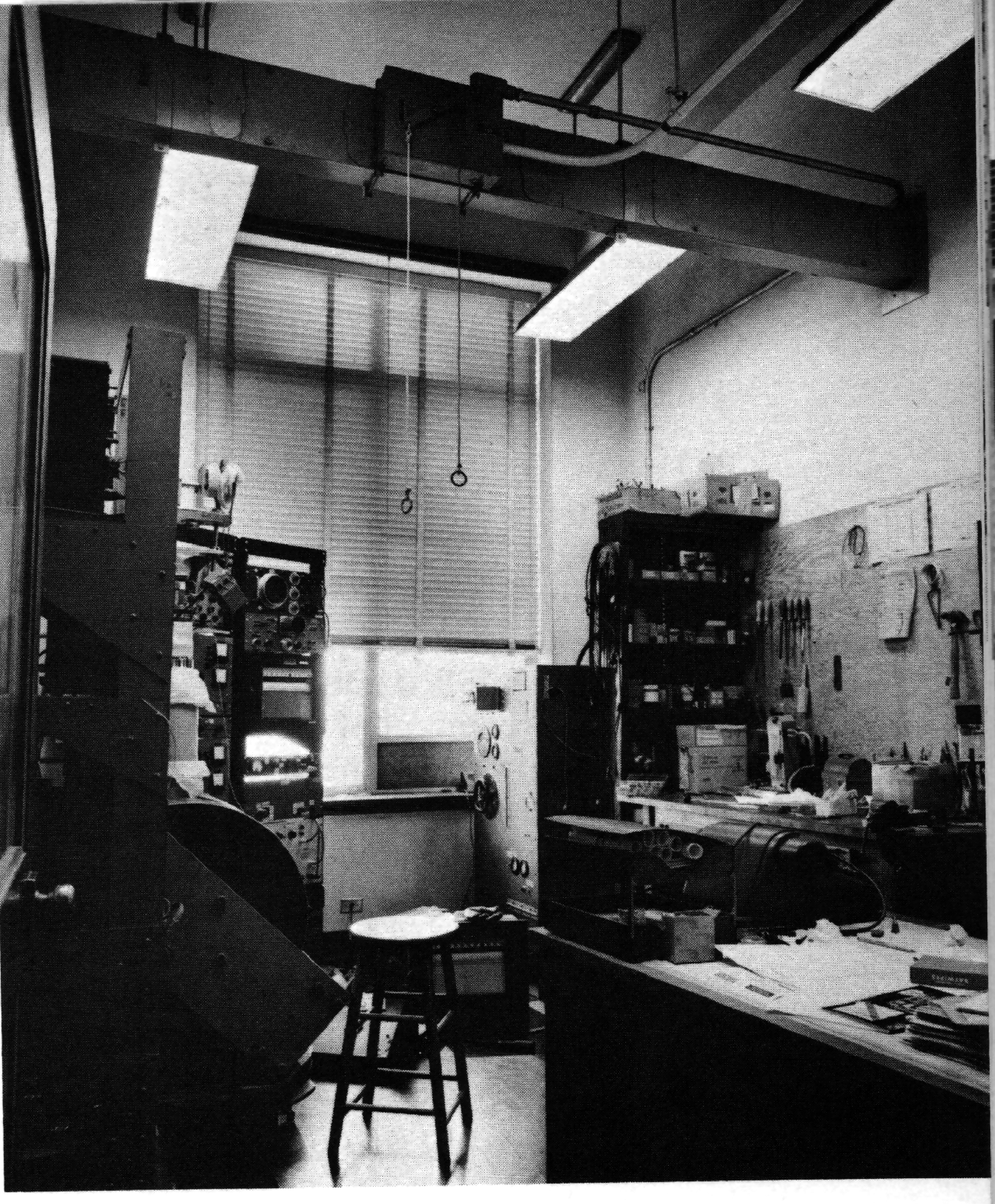


Figure 13. Large ac power requirements are supplied by overhead bus duct which runs through research laboratories in the Le Conte Addition to the Physics Building at the University of California at Berkeley.

Chalkboards

Each research room should have a chalkboard—as large a board as can conveniently be mounted without interfering with other use of the wall. At one institution chalkboards are mounted on the backs of all doors to research laboratories.

Communications

Probably the most versatile communications system is obtained by a generous distribution of telephone extensions, together with a push-button system which allows local dialing and local signaling. Some laboratories supplement this with a building-wide buzzer system by which certain key persons can be called by code. A building-wide intercom system is sometimes installed, though more frequently intercoms are used for communicating between a limited number of rooms which have problems in common.

Double-floor Rooms and Shafts

Physics buildings have been occasionally constructed with a room two stories high to provide for experiments which might require the additional height. Where such space has been provided, a lightweight removable floor was usually installed initially so as to provide two usable rooms until the extra height is needed. Sometimes the extra height has proved to be very useful; many times it has not. Alternative methods of providing for experiments requiring height (such as temporary structures or other buildings on the campus) should be considered before deciding to include such a two-story room in the plans for a new physics building.

It is frequently possible to find space for a small open vertical shaft in a physics building. For example, when a double corridor wall is used for service risers, some of the space can be free for a shaft, in which case doors or removable panels are installed at each floor. Such shafts have occasionally proved useful.

Offices and Research Laboratories

In general, members of the physics staff prefer to have offices separate from, though somewhat near, their research laboratories. Frequently these offices adjoin the laboratories. The separation is desired in part because of noise; also, "to separate the two functions" and "to keep students with questions out of the research areas."

Graduate students and research assistants working in research laboratories are usually provided a small desk in the laboratory. However, if they are simultaneously serving as teaching assistants, they usually meet their students for conference elsewhere at posted hours.

9. Shops and Auxiliary Rooms

INTRODUCTION

Many different kinds of technical services needed by physics departments are provided by facilities such as the following:

1. Machine shop
2. Instrument shop
3. Sheet metal shop
4. Wood shop
5. Student shop
6. Paint spraying shop
7. Electronics shop
8. Glass-blowing shop
9. Darkroom
10. Chemical preparations room
11. Radioisotopes preparations room
12. Space for special services such as high frequency heating and the evaporation of metals
13. Space for storing stock and equipment
14. Space for the storage or production of liquid nitrogen and liquid helium
15. Second-class storage space: the "morgue."

At most colleges several of these facilities may be housed in the same room. For instance, the instrument shop is frequently combined with the machine shop. The wood shop, on the other hand, is usually kept to itself because of the sawdust problem. Sometimes the wood shop is combined with the sheet metal shop, sometimes with the student shop. Paint spraying requires a separate room—one which is equipped with a strong exhaust fan. The physics department frequently turns to the department of buildings and grounds for paint spraying and woodworking, in which case these facilities are not provided in the physics building. Except in large departments, a single room may house the facilities for chemical preparations and the equipment that may be required for such activities as radio-frequency heating and the evaporation of metals.

The extent to which any of these facilities are required by a physics department depends both on the size of the department and on the nature of its research program. The area which must be set aside for them also depends on their availability elsewhere—either on the campus (such as in an all-college machine shop, wood shop, or glass blowing facility) or in a nearby commercial establishment. For instance, certain work can be farmed out if a local machine shop accepts custom work. Also, most departments have found that it does not pay to manufacture their own liquid air if it is available commercially. However, if liquid air is not available commercially, departments requiring it must set aside space for installing their own liquid-air machine.

The area devoted to certain of these facilities in a number of physics buildings is given in the table at the end of this chapter.

SHOPS

The Central Shop vs. the Physics Shop

Many colleges have a central shop which takes care of the shop requirements of all departments. At most schools of appreciable size, however, the physics department maintains an independent shop in its own building even if there is a central shop. Where there is no central shop, the physics shop may take on incidental jobs for other departments. This is a valuable service, and there is no reason why it should not be encouraged as long as it does not interfere with the scheduled work of the department.

Instrument Shop

A shop which employs a number of machinists should have an experienced tool maker—possibly even an instrument maker. Such an individual is not only expert in the use of all machines and hand tools but, in addition, he can turn out good work without having to be given carefully prepared working drawings. He can visualize what is desired, and many times can make helpful suggestions for improving the proposed method of construction and even the basic design of the article desired. He may be provided a separate room with machines and tools which he jealously reserves for his own use. This attitude on the part of an expert machinist is not unreasonable; to get good work out of a machine, particularly as it becomes worn in, the operator must know his machine and know how it is being cared for. Incidentally, it is for this reason, coupled with the inexperience of students and faculty, that certain tools are reserved for the full-time use of the machinists.

Machine Shop Office

An office is desirable even for a small shop. An office provides the foreman a place to keep his records, and a place for him (or other machinists) to discuss shop work with members of the faculty or research staff, away from the noise of the shop. Besides a desk and chair and filing cabinets, if the shop has enough work to justify it, a drawing table can well be installed in the shop office. The office of the foreman in the physics shop at Northwestern University appears at the far left in the background of Figure 1. This room also serves as the instrument repair room.

Location of Shop

The physics shop should not be tucked away in the basement or sub-basement of a building and given only space that is left over after other facilities which seem more closely related to teaching and research have been assigned their space. This will not only result in unpleasant working conditions but will also be inconvenient for handling materials unless special measures are taken. Note, for example, that the physics shop at Northwestern University (Figure 1) is on the ground floor.

At one institution that we visited, the shop was moved from a basement room to a lighter and pleasanter area (with light walls and vinyl tile floors laid over concrete), and a marked improvement in morale of shop staff resulted. At another institution the shop is located in the sub-basement and materials must be carried downstairs and around corners in a tortuous route. If the shop must be located in a basement the access route should be as direct as possible.

As more demands are made upon the services of a shop, new machines are required and more space is needed. Therefore, in selecting the location for the physics shop one should keep in mind its need for expansion and also see that adequate paths are available for bringing in new machines that may be required in the future.

Accessibility to Receiving Area

Furthermore the physics shop should be conveniently located with respect to the receiving area for the building—whether this

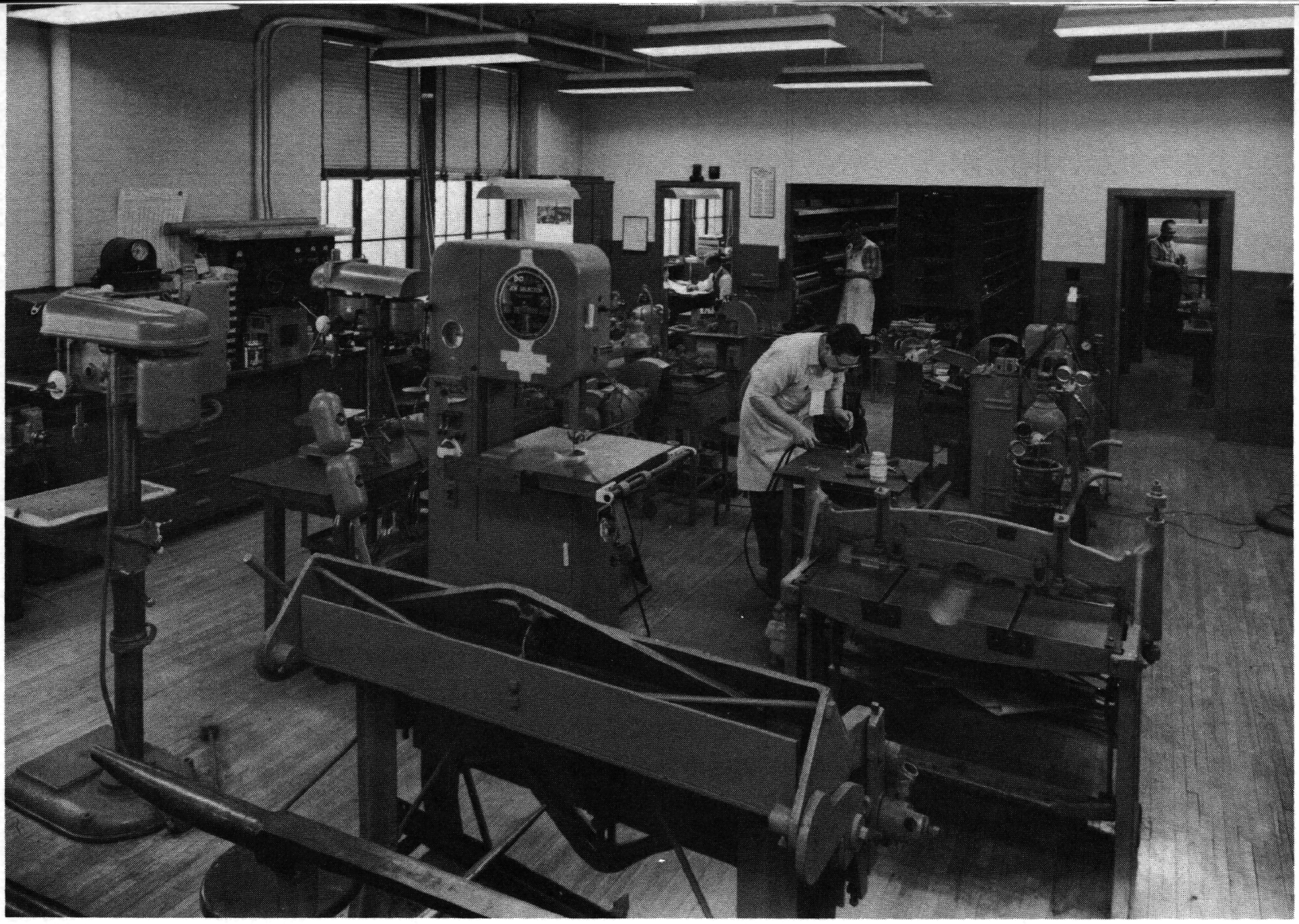
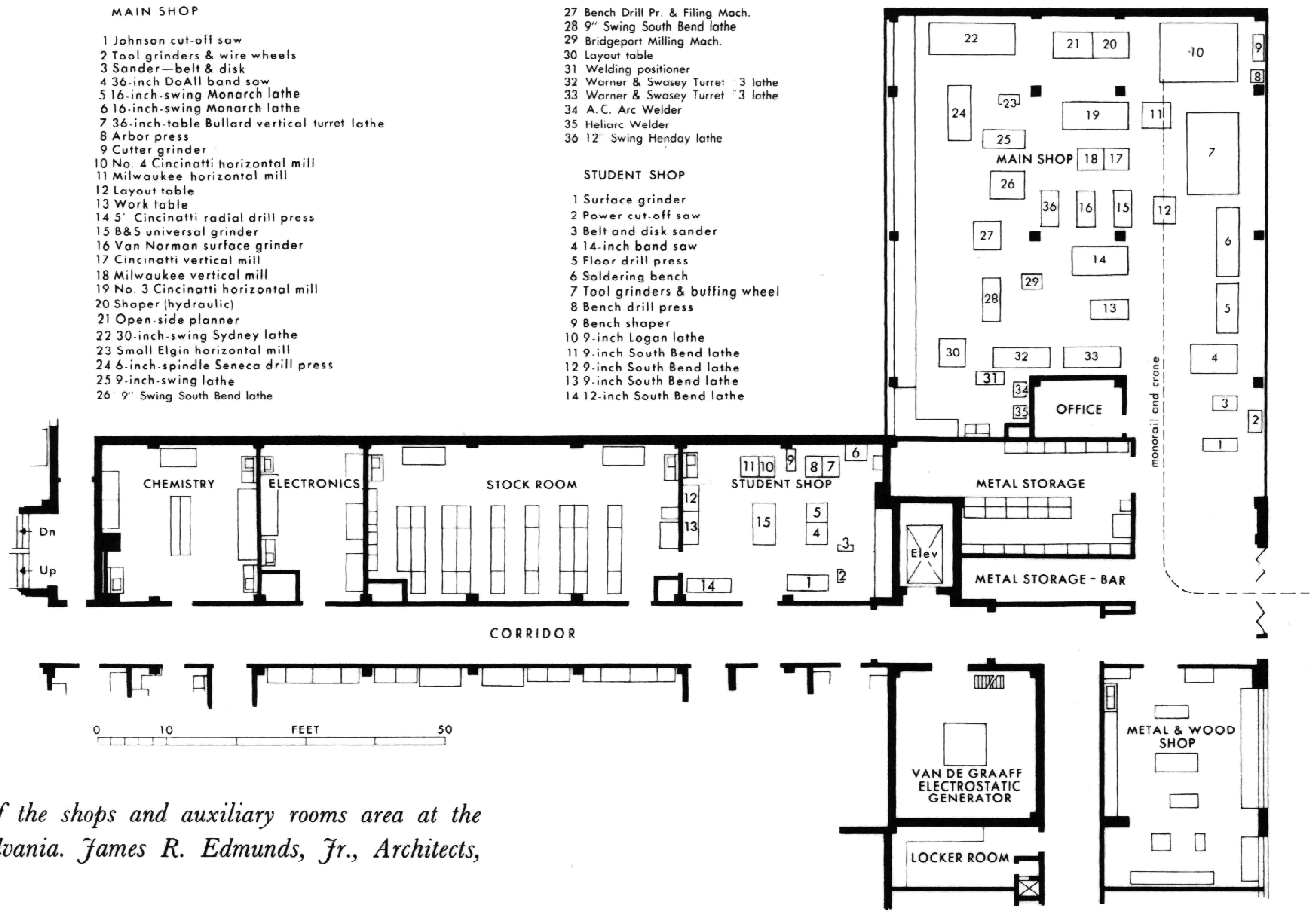


Figure 1. Machine shop in the physics department at Northwestern University.



MAIN SHOP

1	Johnson cut-off saw
2	Tool grinders & wire wheels
3	Sander—belt & disk
4	36-inch DoAll band saw
5	16-inch-swing Monarch lathe
6	16-inch-swing Monarch lathe
7	36-inch-table Bullard vertical turret lathe
8	Arbor press
9	Cutter grinder
10	No. 4 Cincinatti horizontal mill
11	Milwaukee horizontal mill
12	Layout table
13	Work table
14	5' Cincinatti radial drill press
15	B&S universal grinder
16	Van Norman surface grinder
17	Cincinatti vertical mill
18	Milwaukee vertical mill
19	No. 3 Cincinatti horizontal mill
20	Shaper (hydraulic)
21	Open-side planner
22	30-inch-swing Sydney lathe
23	Small Elgin horizontal mill
24	6-inch-spindle Seneca drill press
25	9-inch-swing lathe
26	9" Swing South Bend lathe
27	Bench Drill Pr. & Filing Mach.
28	9" Swing South Bend lathe
29	Bridgeport Milling Mach.
30	Layout table
31	Welding positioner
32	Warner & Swasey Turret 3 lathe
33	Warner & Swasey Turret 3 lathe
34	A.C. Arc Welder
35	Heliarc Welder
36	12" Swing Henday lathe

STUDENT SHOP

1	Surface grinder
2	Power cut-off saw
3	Belt and disk sander
4	14-inch band saw
5	Floor drill press
6	Soldering bench
7	Tool grinders & buffing wheel
8	Bench drill press
9	Bench shaper
10	9-inch Logan lathe
11	9-inch South Bend lathe
12	9-inch South Bend lathe
13	9-inch South Bend lathe
14	12-inch South Bend lathe

MAIN SHOP
OFFICE
monorail and crane
CHEMISTRY
ELECTRONICS
STOCK ROOM
STUDENT SHOP
METAL STORAGE
Elev
METAL STORAGE - BAR
Dn
Up
CORRIDOR
0
10
FEET
50
VAN DE GRAAFF ELECTROSTATIC GENERATOR
LOCKER ROOM
METAL & WOOD SHOP

Fig. 2. Floor plan of the shops and auxiliary rooms area at the University of Pennsylvania. James R. Edmunds, Jr., Architects, Baltimore.

area is a special room with its own dock for receiving goods delivered to the building or simply an open corridor adjacent to a side door. The floor plan for accomplishing this for the shop area at the University of Pennsylvania is given in Figure 2. It will be noticed that the service entrance opens into a receiving area which is immediately adjacent to the machine shop, the wood shop, and the ground floor corridor. Furthermore, a freight elevator is conveniently located in the adjacent corridor. Note the use of an overhead monorail and 2-ton crane for transferring heavy items from the receiving area into the shop. A 3-ton fork-lift truck is also available for moving equipment in this area.

A dock which is at truck bed height is a convenience for loading and unloading heavy items. When the receiving area is at ground level and such a dock is not provided, unloading heavy items requires special equipment, usually a portable crane. Alternatively, a hydraulic platform lift that can be brought to the required level can be installed as at the Jefferson Physical Laboratory at Harvard University (Figure 3).

The McKay Laboratory at Harvard has provision for receiving both at truck bed height and at ground level, as shown in Figure 4.

Lighting

The general level of illumination in a shop should be about 30 foot candles with supplemental lighting on work to bring the level to at least 50 foot candles. The supplemental light at individual machines is usually supplied by clamp-on lamps or lamps which are designed for the machine. These auxiliary lamps are normally incandescent because of the undesirable stroboscopic effect when moving objects are illuminated by fluorescent lamps. When fluorescent lamps are used for general illumination in a shop, the stroboscopic effect is not objectionable if the lamps in adjacent fixtures are connected to different phases of the 120/208 volt 3-phase lighting circuit. Light fixtures should be mounted close to the ceiling to provide as much clearance above machines as possible. Storerooms need no more than about 10 foot candles of illumination except in the vicinity of the storage of small parts where a higher level is needed.

Acoustics

The principal acoustical problem in connection with a shop is the reduction of the noise produced in the shop. The noise level is usually not excessive in a small shop, but it does become significant in a large shop where a number of machines may be operating at the same time. The noise created does not normally disturb other areas in the building since the activities that need quiet are usually well removed from the area of the shop. If they are not, the walls and ceilings of the shop should be extra heavy; the doors should be heavy and kept closed. However, for the comfort of the machinists, it may be desirable to suspend acoustical absorbers at intervals from the ceiling to reduce the noise level. Acoustical absorbers interfere less with pipes and conduit than would a standard acoustical ceiling. In addition to increased comfort, a lower noise level makes it possible for machinists to confer with each other and with members of the research or teaching staff without having to leave the shop.

Power

The ac power required for operating the machine tools in a shop is supplied in various ways, usually by conduit, either from overhead or from the floor. However, a much more flexible (though initially more costly) arrangement consists of an overhead bus duct system similar to the General Electric Flex-A-Power or Westinghouse Life-Line. These are plug-in type systems, and tap-off fittings with fused switches or circuit breakers are available for almost any load requirement up to about 400 amperes at 220 volts. Such duct systems are usually suspended by hang-

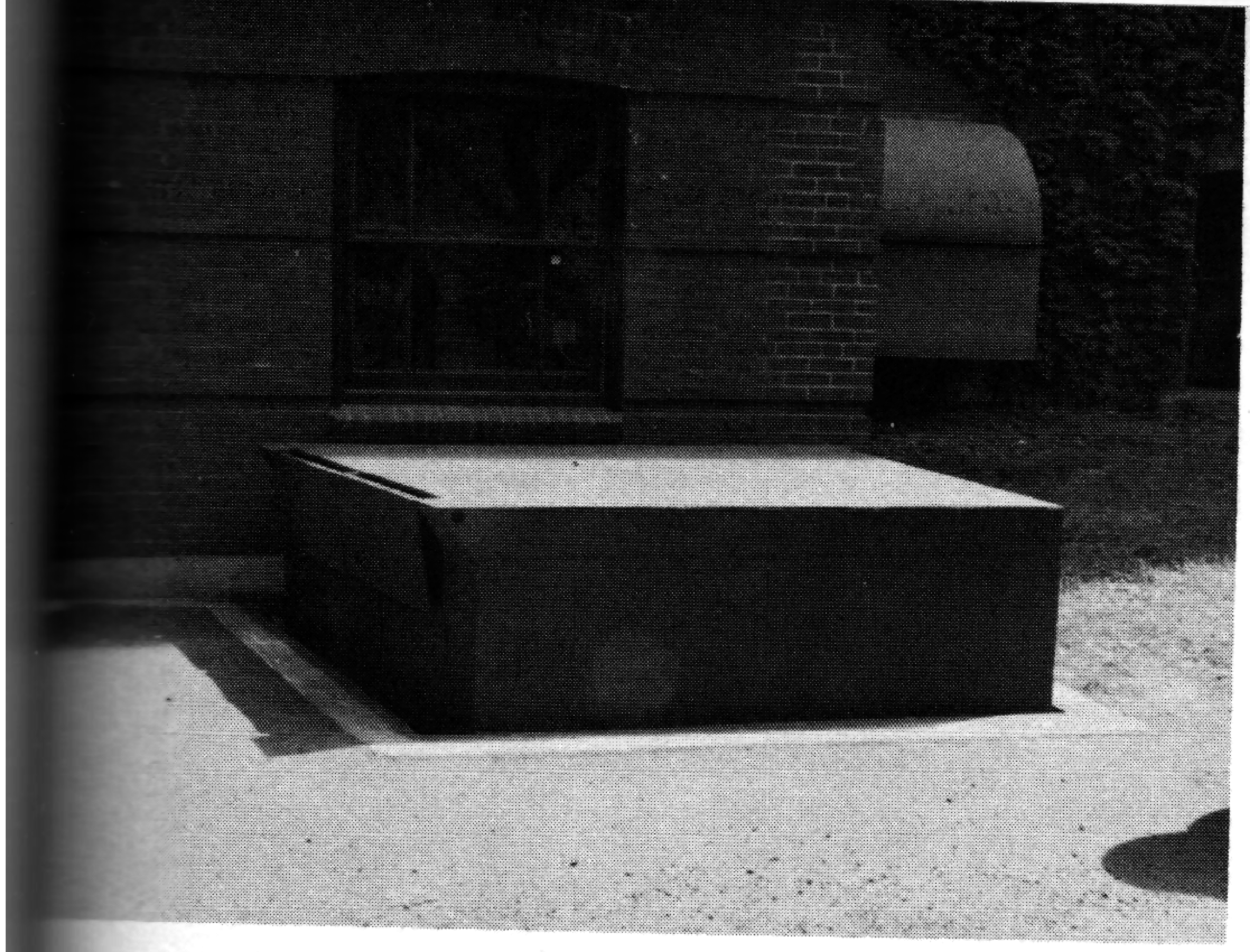


Figure 3. Hydraulic platform lift for the Jefferson Physical Laboratory at Harvard University.

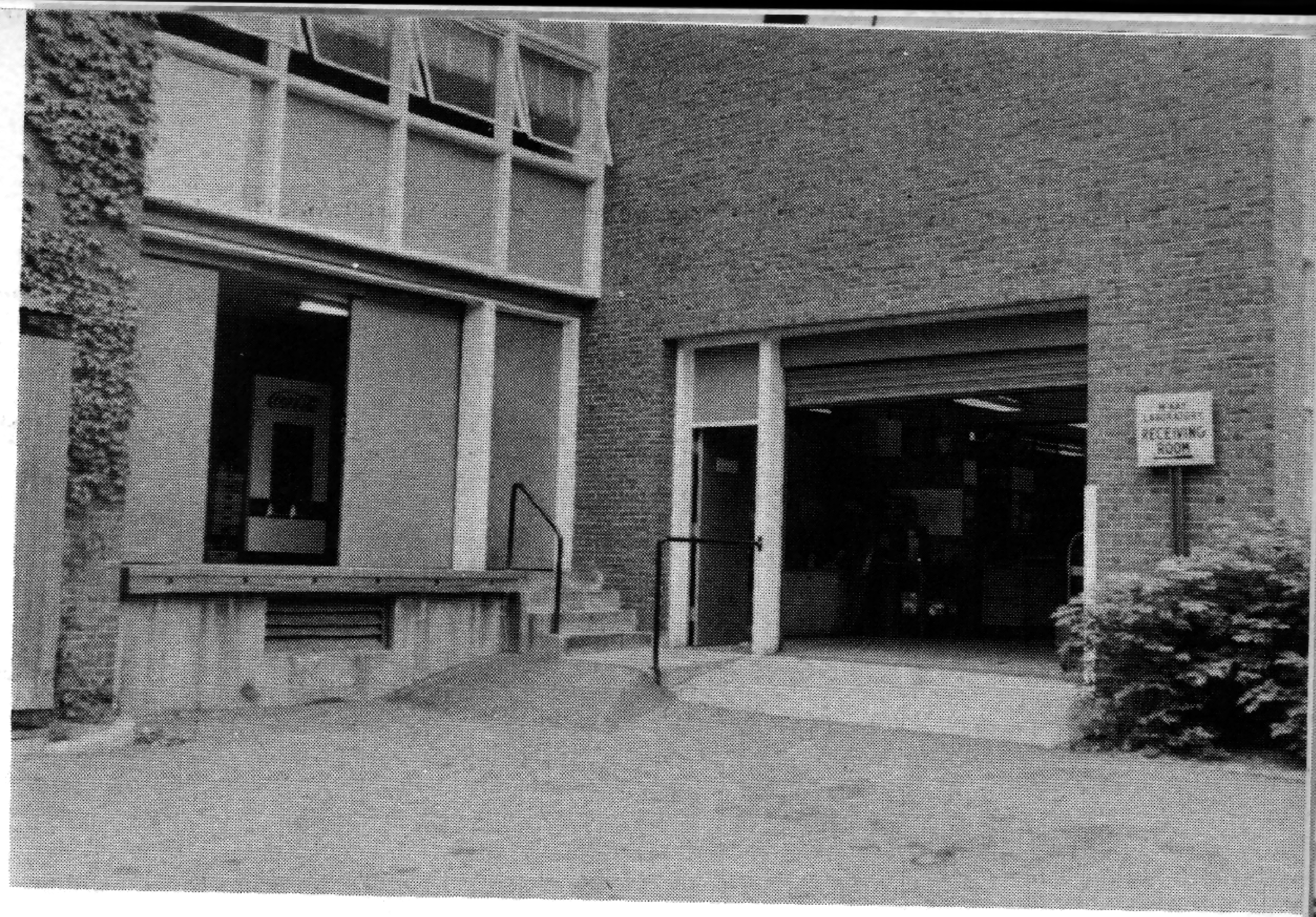
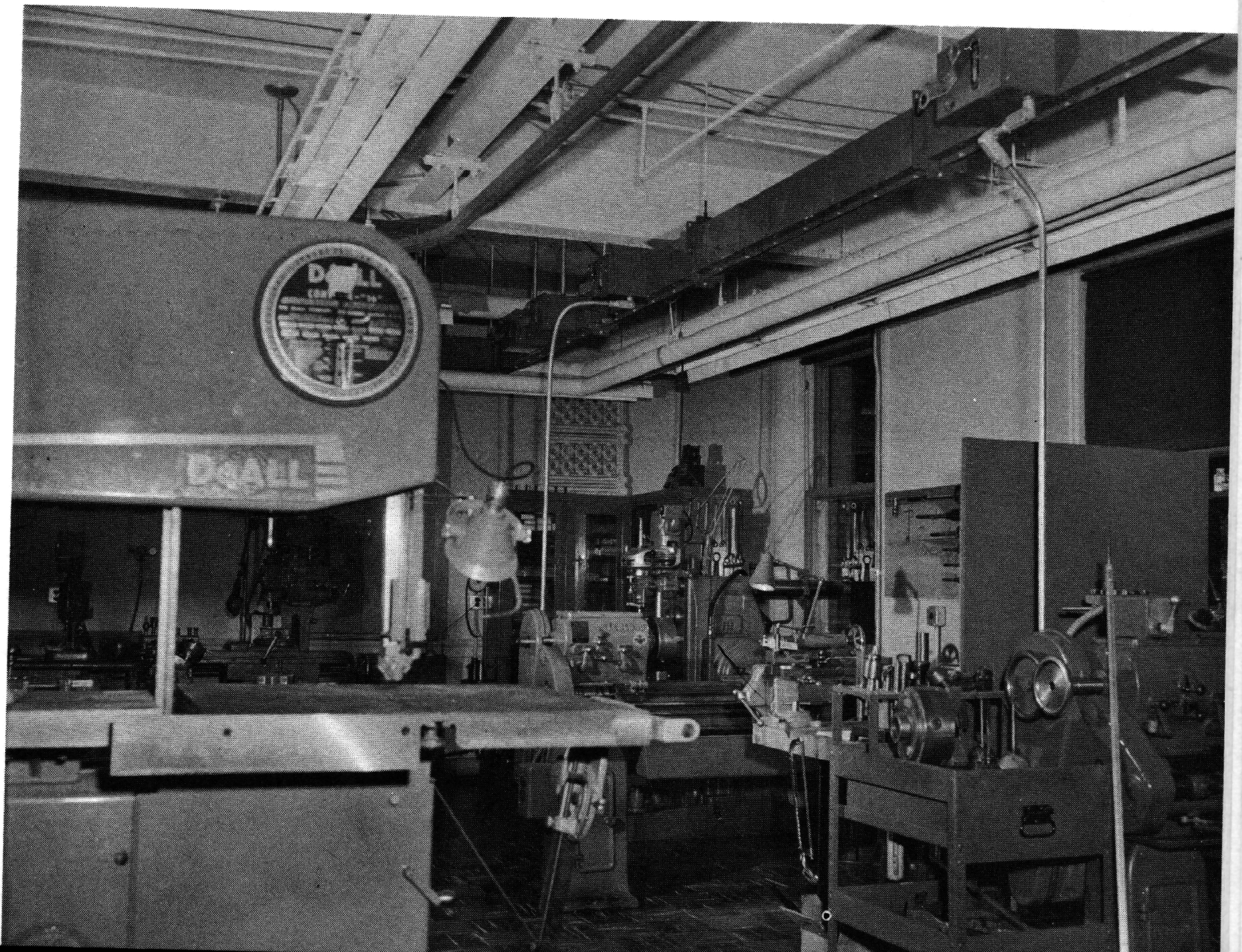


Figure 4. Receiving area for the McKay Laboratory at Harvard University.

ers from the ceiling, with two or three ducts running the length of the shop. Machines can then be placed at almost any spot in the shop and connecting them to the bus duct is a simple operation. Bus bar has the added advantage of having a high current rating and thus a very low line loss compared with wire in conduit. This is particularly important for starting machines under load and for continuous heavy load. Figure 5 shows bus duct installed in the physics shop at Case Institute of Technology.

Figure 5. Machine shop at Case Institute of Technology. Note use of overhead bus duct.



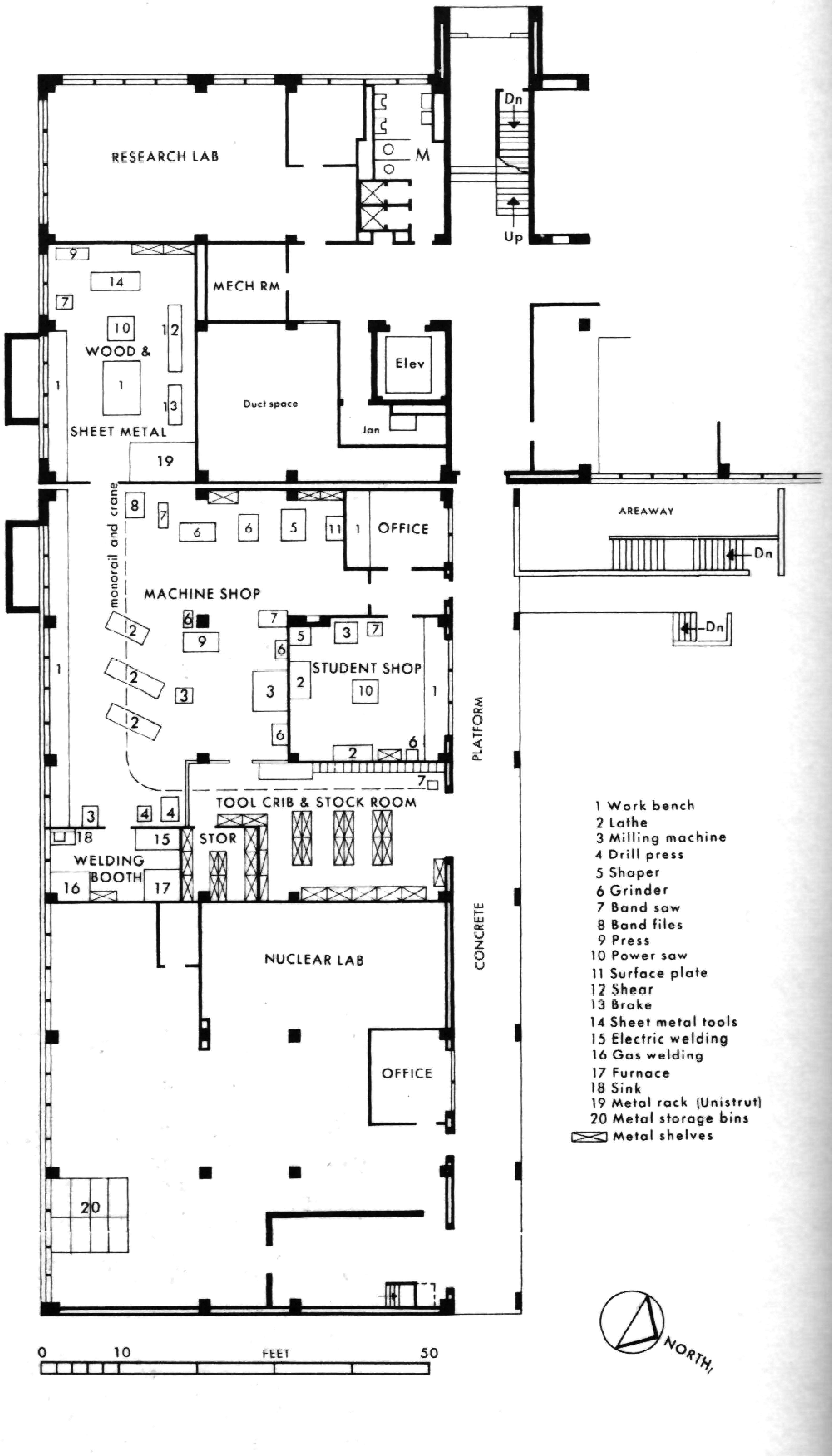
A cheaper and yet flexible system consists of a simple sheet metal duct which is hinged on one side for easy access. Cables are simply laid in the duct, and box outlets are attached where required. The boxes should contain either separately fused switches or circuit breakers.

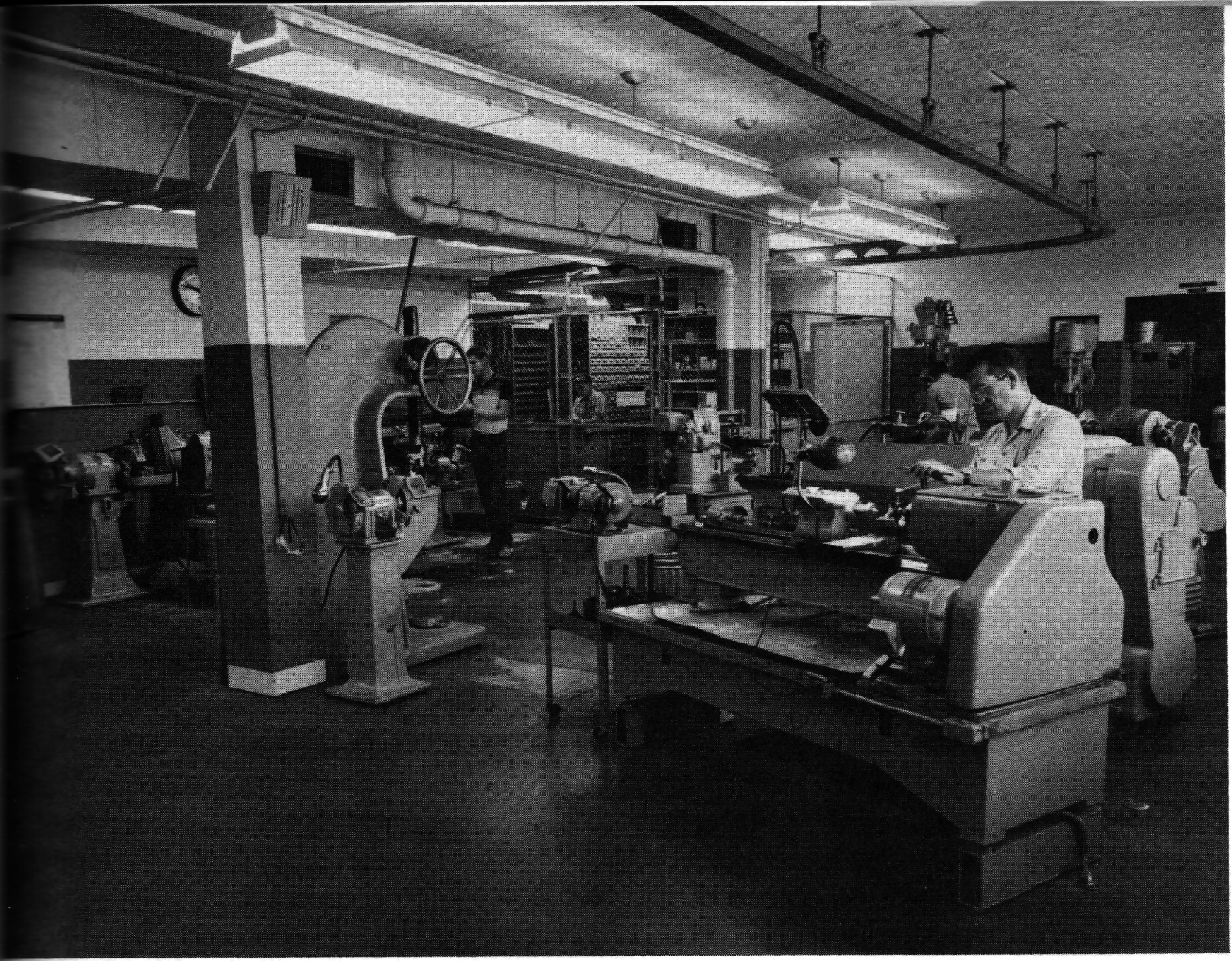
The normal 4-wire 120/208 volt 3-phase ac system currently being installed in most new physics buildings will accommodate either the 120 volt single phase or the 220 volt 3-phase motors which are standard equipment for most machine shop tools. Special machines—particularly some of those available on government surplus—may require 440 volts 3-phase. The size of wire or bus bar required must be determined by an analysis of the power requirements taking into consideration future machines that may be added to the shop.

Shop Tools

The physics shop is a custom shop—the jobs taken on are usually one-of-a-kind, except in very large departments where introductory physics laboratory equipment is constructed in fairly large quantities. When a large number of pieces of apparatus all of the same kind are to be built, many departments find it cheaper to let the job out to a commercial shop with only the prototype made in the physics shop. The custom character of the physics shop means that it is called upon for a variety of jobs and must therefore be equipped with a variety of tools. However, since budgets must be considered, when a shop is first established the tools which are the most basic and the most versatile should be purchased first. Beyond the need for a good set of hand tools, work benches, an assembly table, and a few powered machines such as a lathe, drill press, milling machine, metal saw and grinder, the priority in which the rest should be ordered depends not only on the type of work most likely to be done but also upon the personal preference of the machinists.

Three lists of tools for three different size shops are given at the end of this chapter. The lists are not presented as ideal examples but merely to provide suggestions as to what types of machines should be considered in planning a new shop. The lists of tools which accompany the layouts of the shops at the University of Pennsylvania (Figure 2) and the University of Florida (Figure 6) may also be useful.


RESEARCH LAB
M
Dn
Up
MECH RM
WOOD &
SHEET METAL
Elev
Duct space
Jan
monorail and crane
OFFICE
MACHINE SHOP
STUDENT SHOP
AREAWAY
Dn
Dn
PLATFORM
TOOL CRIB & STOCK ROOM
STOR
WELDING BOOTH
NUCLEAR LAB
CONCRETE
OFFICE
0
10
FEET
50
NORTH
1 Work bench
2 Lathe
3 Milling machine
4 Drill press
5 Shaper
6 Grinder
7 Band saw
8 Band files
9 Press
10 Power saw
11 Surface plate
12 Shear
13 Brake
14 Sheet metal tools
15 Electric welding
16 Gas welding
17 Furnace
18 Sink
19 Metal rack (Unistrut)
20 Metal storage bins
Metal shelves



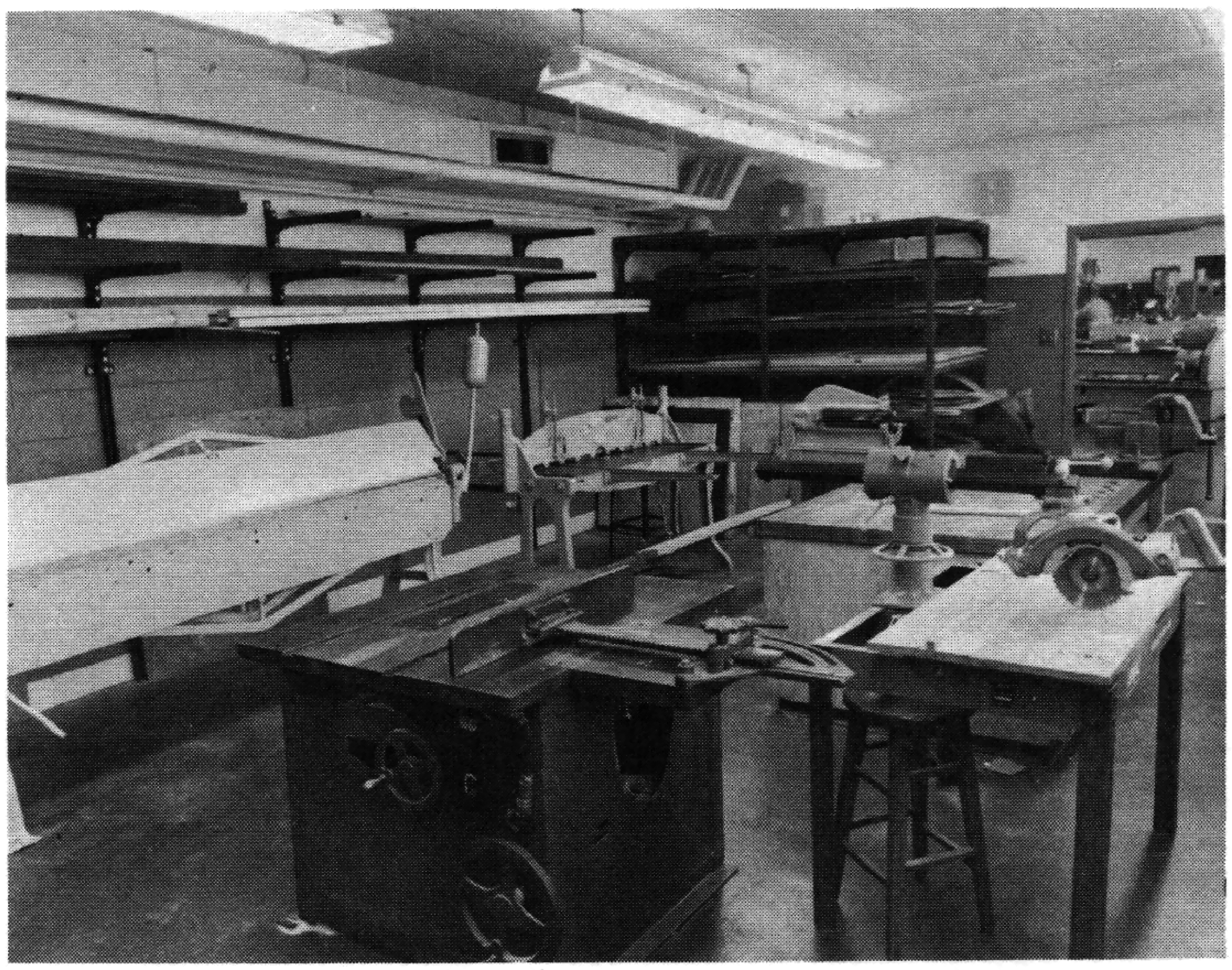


Figure 6. Shops and receiving area, University of Florida. (See Figure 3, Chapter 4.) Note overhead crane and layout of lathes in machine shop (shown above). In wood and sheet metal shop (right), Unistrut is used for constructing frames for shelves. Receiving dock with roll-up door open is shown below.

UNIVERSITY OF FLORIDA

Both the tops and the bases of shop benches and assembly tables should be sturdy. Tops, 2½ inches thick, composed of narrow strips of maple glued together, are widely used.

Shop Layout

In laying out a shop, consideration must be given to both efficiency and safety. Templates representing the machines should be used along with a floor plan of the shop to determine the most desirable arrangement of machines. Machines are normally placed in line, both for the sake of appearance and to be able to supply power from a single power line overhead or in the floor. However, in doing so both the spacing and the orientation must be considered. Both safety and efficiency are promoted by allowing plenty of space between machines. Adequate space for freedom of movement should be available to the operator. Machines in line are frequently oriented at an angle rather than square with the room. This not only minimizes the chance that flying parts will injure a workman at an adjacent machine but it also allows long stock to project a greater distance. This is particularly important in the case of lathes. (See Figure 6.)

Floors

The floor in most physics shops is bare concrete that has received the standard hardening treatment. Most machinists prefer a wood floor, either strip maple boards or small maple blocks on end. They believe that such a floor is less tiring on the feet than hard concrete. Furthermore, cutting tools and delicate pieces of apparatus are less apt to be damaged when dropped. A maple strip floor is laid in the shop at Northwestern University (Figure 1). For these same reasons, either asphalt tile or vinyl asbestos tile had been laid over concrete in some of the shops we visited. The hardness of concrete does, however, work to advantage in a shop; it is easier to maintain than floors of wood or tile since metal chips do not get embedded in the floor. If necessary, machinists can be furnished mats at their work positions to ease their feet.

The Student Shop

In a department which has only one shop, both faculty and students are usually allowed to use the machines even if a special technician is employed. As a shop grows, obtains precision equipment, and takes on expert machinists, students must be excluded, and it becomes necessary to establish a separate shop for their work. The student shop is normally less elaborately equipped than the main shop. Its machines are likely to be old machines that have been removed from the main shop when new machines are purchased for it. However, considerable training value derives from allowing students to use power tools to build experimental apparatus, and therefore most physics departments try to provide such facilities for their students.

A list of tools in the student shop in the Electronics Research Building at the Lawrence Radiation Laboratory at Berkeley is given at the end of this chapter.

AUXILIARY ROOMS

Electronics Shop

Electronics is becoming so important in instrumentation that most research laboratories find it desirable to establish a separate electronics shop, staffed with the required technicians. The space set aside for this purpose at several representative institutions and the number of technicians employed is given in a table at the end of this chapter.

The principal need for utilities in an electronics shop is for 120 volts ac, and this should be distributed generously. The simplest installation utilizes surface mounted multi-outlet strips running along the wall at the back of each work bench and about 1 foot above the bench top, with additional strips also frequently mounted on the front of the bench just below the overhanging top. It may be convenient to install coaxial cables and a pair of free lines between individual benches and a central station where such devices as a signal generator or special voltage sources are located. A good electrical ground should be available at each bench.

The furniture in an electronics shop must include chests of drawers with a variety of drawer sizes for storing miscellaneous parts, as well as cabinets, shelves and bins. For good service, the tops of work benches should be made of strip maple. However, a number of laboratories find that pressed wood (Masonite) over a cheaper wood top is quite satisfactory and more economical even though the surface may need to be replaced occasionally. Figure 7 shows the type of bench used in the electronics shops in the Lawrence Radiation Laboratory at Berkeley. Commercial steel cabinets and chests of drawers alternate with open spaces beneath the bench, thereby providing leg room for technicians seated at their work.

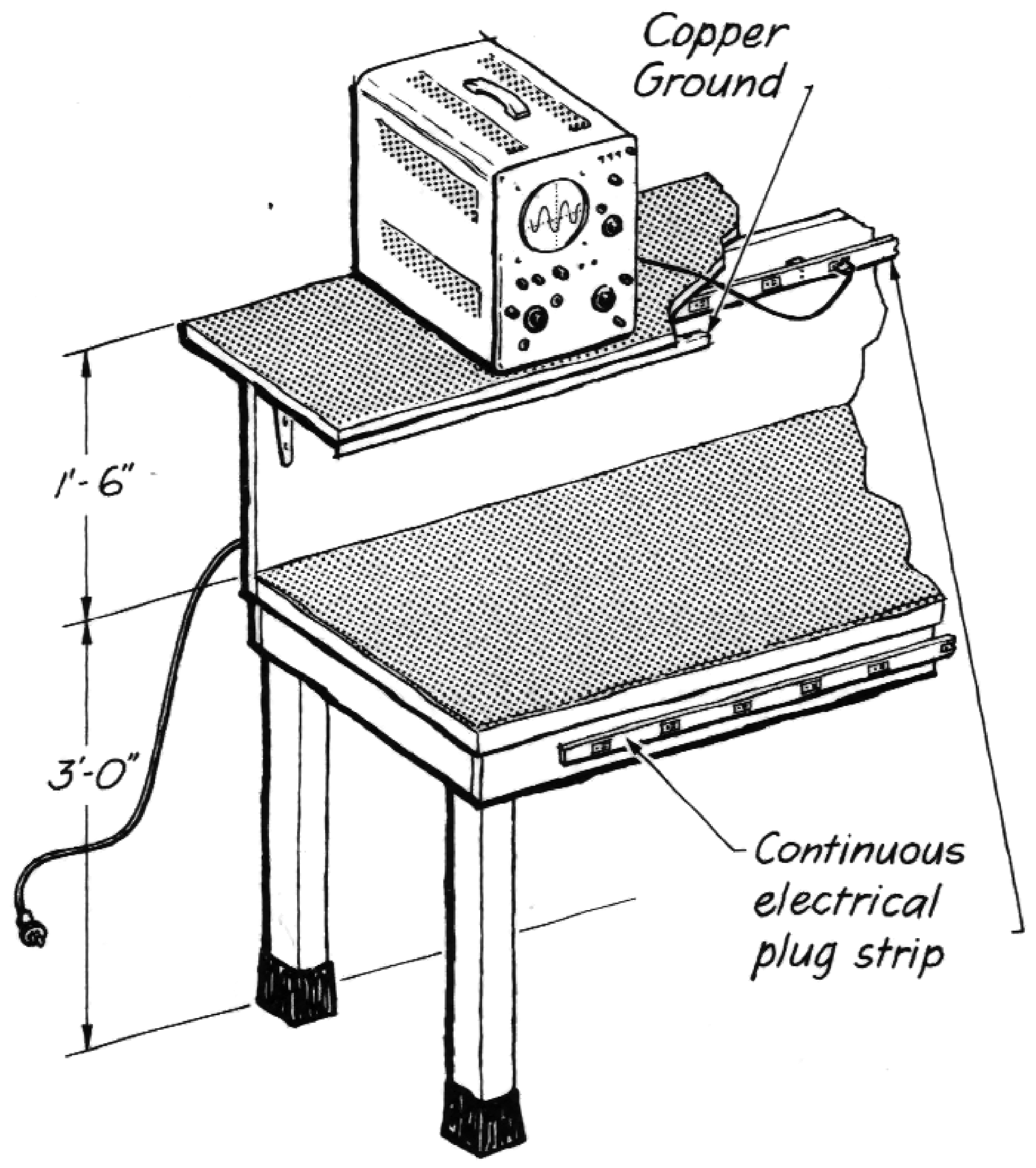


Figure 7. Sketch of electronics bench used at the Lawrence Radiation Laboratory, Berkeley.

Darkrooms

The careless use of a photographic darkroom soon reduces its effectiveness for good work. Spilled chemicals evaporate and leave powders which get carried into the air; they can do irreparable damage when they settle on undeveloped films and plates. If a darkroom is to be properly controlled, its use must be limited to a small number of trained persons and one person should be responsible for its supervision. For this reason, several darkrooms are usually provided in physics buildings—separate darkrooms for work in such areas as spectroscopy, photography, and nuclear emulsions; and even the general purpose darkroom (if there is one) is kept under lock and key.

The size of a darkroom and how completely it is furnished depend on the extent of its use, the number of persons served, and the type of work done. A small research group may require no more than 30 or 40 square feet in one corner of their laboratory in which case the darkroom may have the bare minimum of furnishings—sink, drainboard, shelf or cupboard for photographic supplies, and several electric service outlets. When a larger number of persons have reason to use a particular darkroom at various times, it must be large enough to provide storage for the separate photographic supplies required by each individual and also provide the special facilities which may then be needed.

In any event, it is well to separate any darkroom into "wet" and "dry" areas. The wet area contains a sink and storage facilities for solutions; all work with solutions is done in this area. The dry area provides facilities for storing sensitized materials, and a work bench for operations involving these materials.

If a darkroom is used extensively or by more than one person it is advisable to provide either a light trap or a walk-in arrangement at the entrance instead of a single door that can only be opened safely when the room is not in use. A light trap need take up

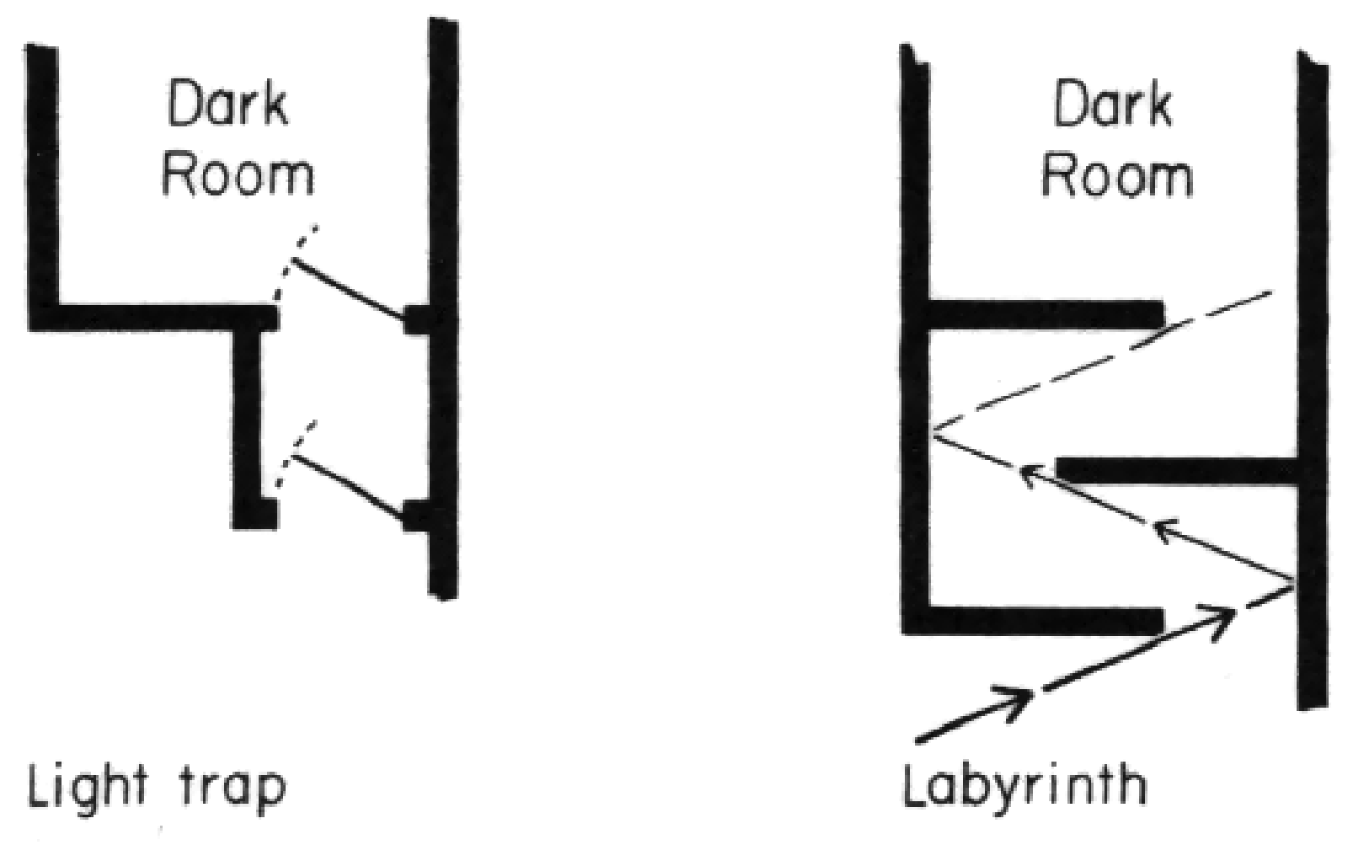


Figure 8. Layouts of entrances to photographic dark rooms: light trap (left); walk-in arrangement (right).

no more than about 4 by 4 feet of space as shown in Figure 8a. Its doors should be at least 2½ feet wide, and be provided with light-tight louvers for ventilation. A warning buzzer or light should be installed to reduce the possibility of both doors being opened at the same time. A walk-in arrangement requires at least twice as much space and can take any one of a number of possible forms such as that sketched in Figure 8b. The passageway for such a labyrinth must be narrow, painted a dull black, and have sufficient turns so that the most extreme ray from an adjacent lighted room would have to make at least two reflections before striking an interior wall of the darkroom. Less light is admitted if the ceiling is low or if it is baffled at a height of about 7 feet. However desirable it may be to conserve space, for reasonable ease of access, the passageway should provide a clearance of at least 2½ feet throughout. To simplify moving furniture through a labyrinth such as that shown, a light-tight door could be installed in the central panel (and normally kept locked), or a section of the panel could be removable, to give a straight path into the darkroom.

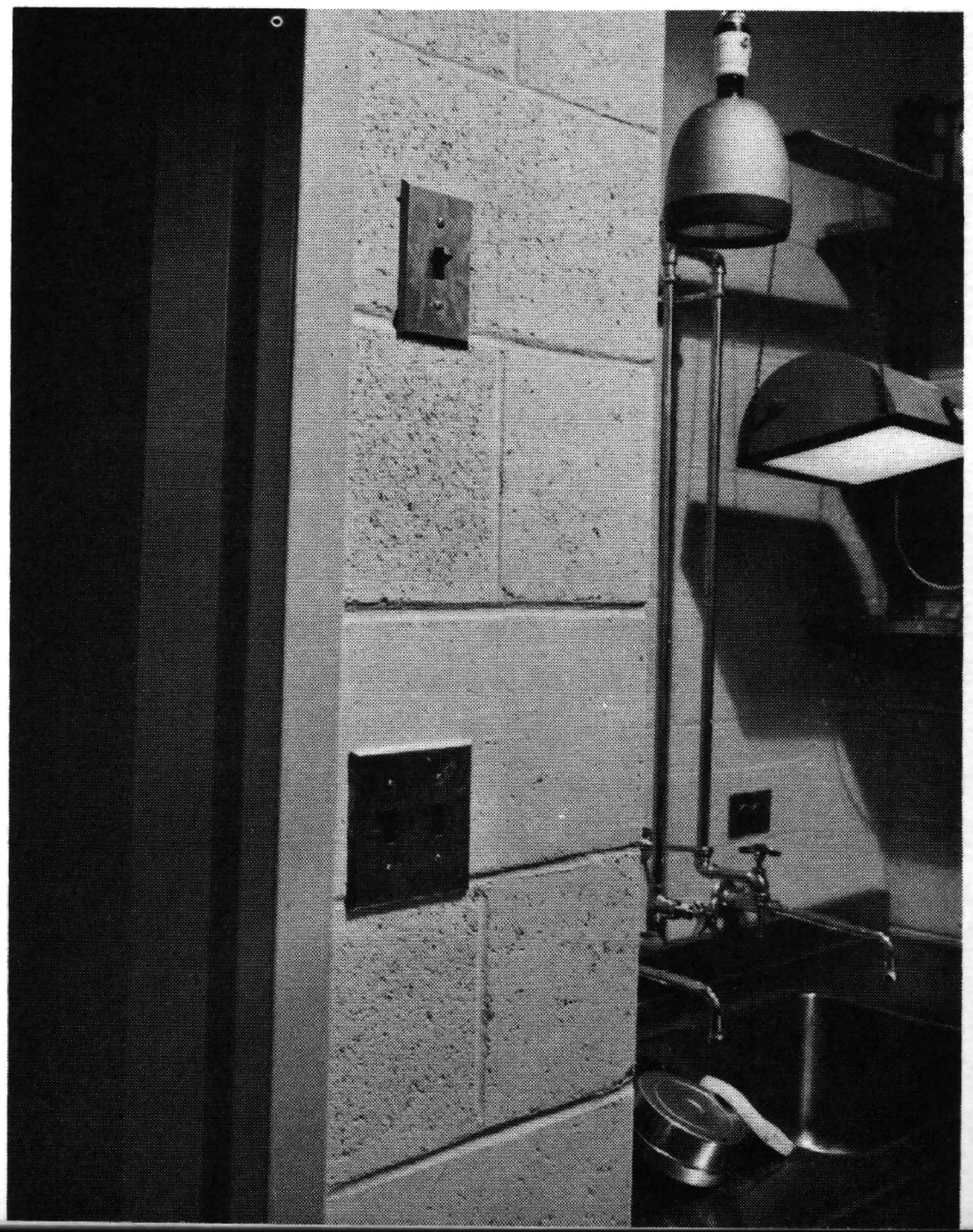
The floor covering in a darkroom should be non-porous and easy to clean since processing solutions are occasionally spilled. Dark-colored asphalt tile is recommended. It contains more asphalt and is thus more chemically resistant than the lighter tile.

The sink in a darkroom should have a flat bottom and be large enough to accommodate three of the largest trays that are normally used. It must be chemically resistant. High quality Alberene, Grade 25, is recommended. So also is the more chemically resistant grade of stainless steel specified as "American Iron and Steel Institute Type 316 of 18-8 stainless steel." This grade contains 18% chromium, 8% nickel, 2 to 3% molybdenum and a maximum of 0.08% carbon. The faucet should be high enough so that a tall jar or gallon jug can readily be filled. If hot water is available, two faucets should be provided—a swinging faucet for mixed hot and cold water and a separate cold-water faucet with hose attachment for rinsing.

Refrigeration equipment or other means of controlling the temperature of solutions is needed for much work with photographic emulsions. A refrigerator may also be desired for storing photographic plates.

All safelights should have individual switches but also be connected to a common switch located at waist height just inside the door to the darkroom. If the switch for the white room light is near the door it should be at shoulder height so it is less apt to be operated accidentally. (See Figure 9.) The

Figure 9. Research dark room in the physics building at the University of Illinois. Switches at normal height are for dark room safelights; switch at shoulder height controls white room lights.



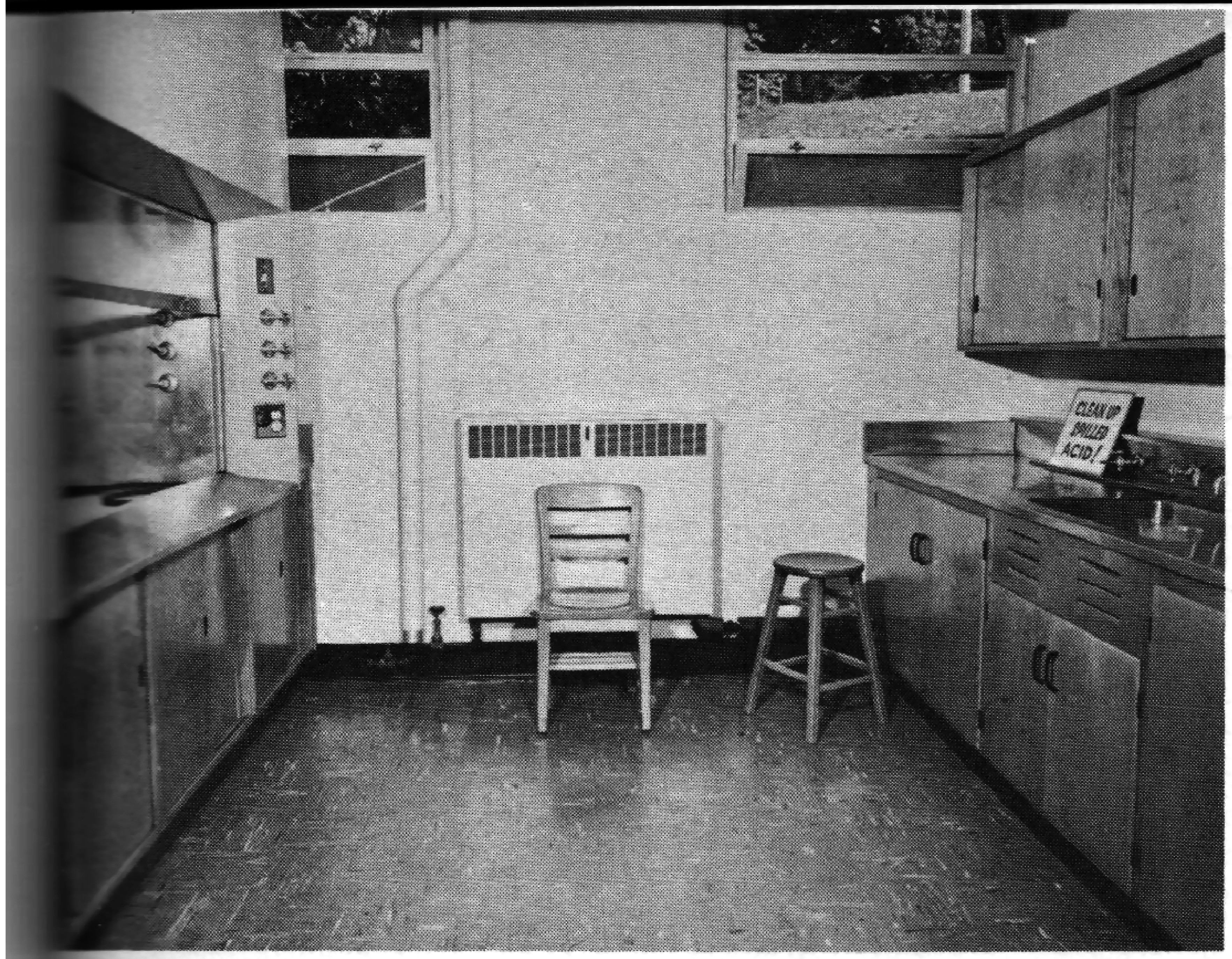


Figure 10. Chemical preparations room in new addition to physics building at the University of Wisconsin.

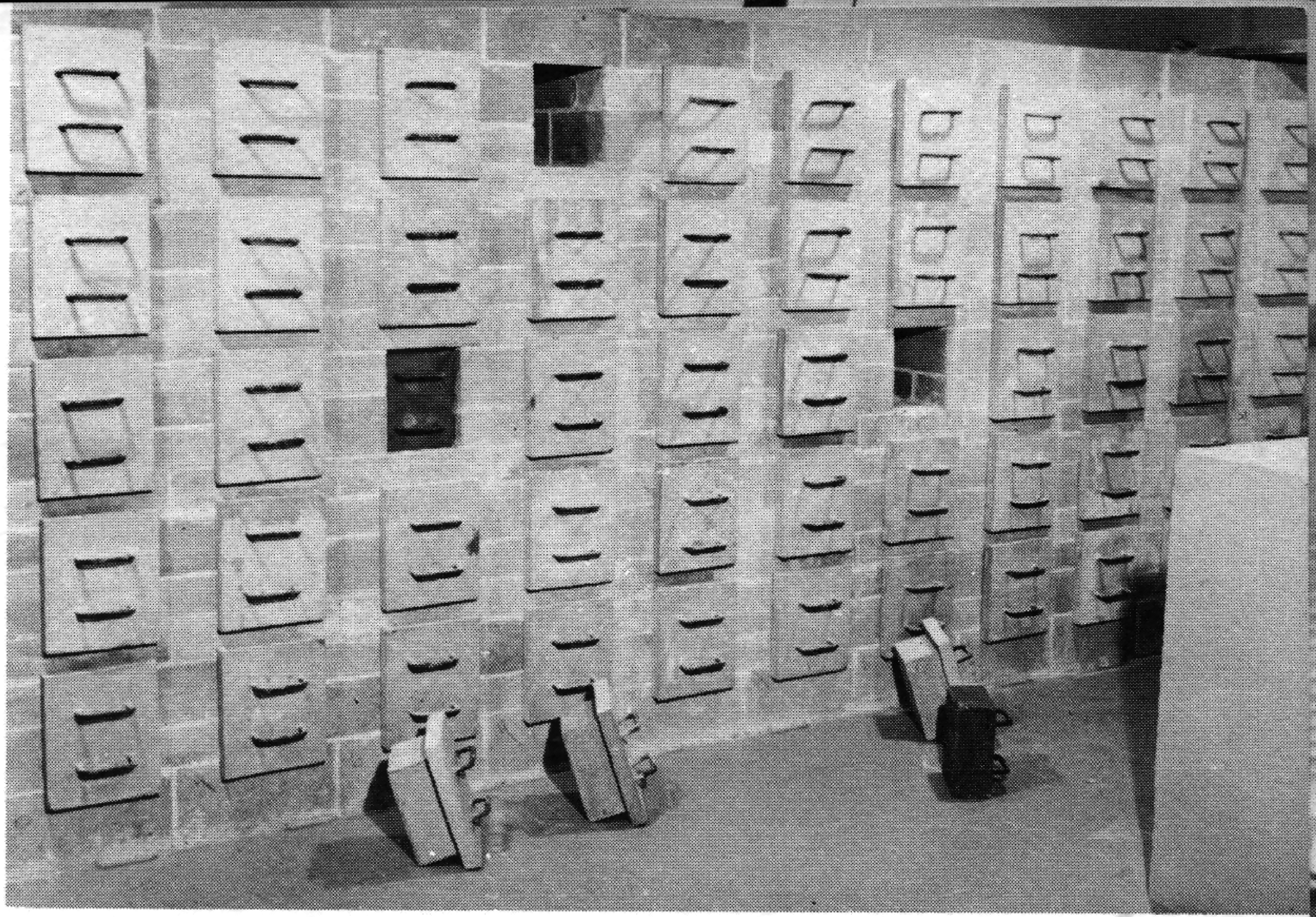


Figure 11. Radioactivity materials storage in physics building at the University of Illinois.

room light switch is sometimes located across the room for the same reason. Incandescent lamps should be used for room light rather than fluorescent lamps since the afterglow from the latter can fog film for a short time after lights are turned out. A red signal lamp outside the door should be connected to the safelight circuit to indicate when the room is in use.

The ventilation for a darkroom should be so designed that air is brought in at the dry end of the room and exhausted near the wet end so that vapors from trays and sinks will be immediately exhausted.

For further suggestions on darkroom design one can refer to standard texts on photography or to pamphlets such as Eastman's *Darkroom Design and Construction.*[1]

Chemistry Preparation

Because of the occasional need to prepare chemicals for certain research projects it is desirable to have an area that is set aside for the purpose. A separate room is to be preferred if the use warrants it. A laboratory bench with a top that is corrosion resistant (stone or composition stone), a cabinet for storing commonly used chemicals, and a simple hood with an exhaust fan complete the required furnishings. The utilities required include a sink with cold water, compressed air, gas, and 120 volt 60 cycle ac. Emergency measures include a deluge shower, eye-wash fountains, fire blanket and fire extinguishers. These safety devices should be located at the entrance to the laboratory so that everyone will be made more aware of their availability. An escape door or window into an adjacent room should be available in a chemical preparation room if the room otherwise has but one exit. Figure 10 shows the small chemistry preparation room in the research wing recently added to the physics building at the University of Wisconsin.

Radioactivity Facilites

Radioisotopes are frequently used in physics research, and their safe handling requires special provision for the manipulation and storage of radioactive materials, the radiochemical preparation of sources, and the disposal of radioactive wastes. Figure 11 shows how concrete blocks have been assembled to provide an array of small caves in which radioactive sources can be safely stored in the new physics building at the University of Illinois. The entrance to each cave can be closed with a concrete plug. The room for

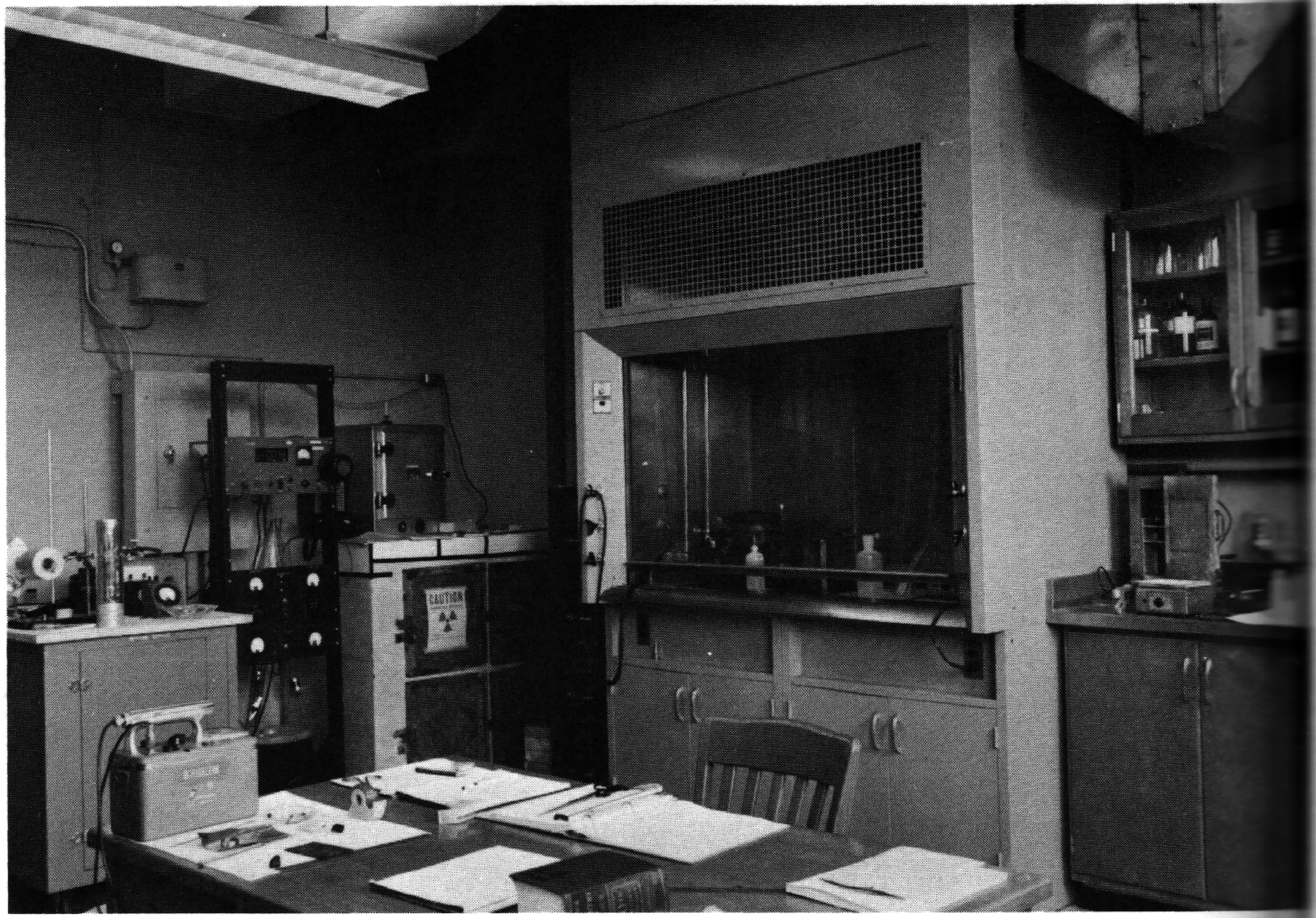
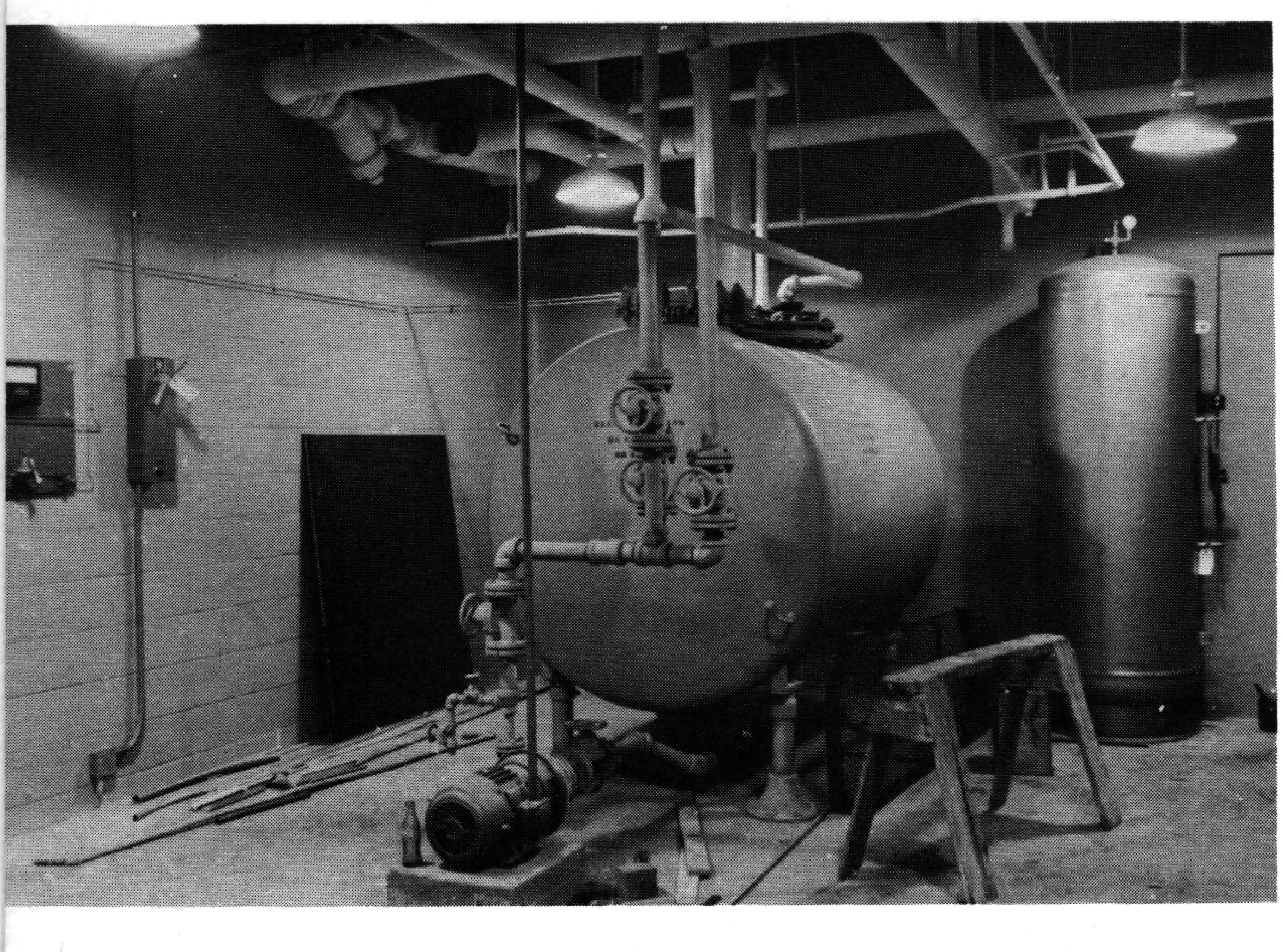


Figure 12. *Radioisotopes preparations room in physics building at University of Illinois.*

radiochemical preparations is shown in Figure 12. Such a room requires a good hood and exhaust fan and other standard chemical preparations facilities. The principle requirement is that surfaces can easily be cleaned in case of a spill. Top quality stainless steel is called for on work benches, for sinks and in hoods (AISI Type 316, described in the section on Dark Rooms). The floor should be covered with non-porous material; some prefer vinyl asbestos tile, because only a small section would need to be replaced in case of a spill; others prefer linoleum, because a continuous surface would not have cracks in which spilled radioactive materials could lodge. Radioactive wastes must be carefully disposed of. Liquid radioactive wastes are pumped into a tank in a basement room in the physics building at Illinois (Figure 13).

Further details on the handling of radioactive materials will be found in such publications as the National Research Council—National Academy of Sciences Conference report entitled *Laboratory Design for Handling Radioactive Materials*[2] and the chapter on "Laboratories for Radioactive Research" in *Buildings for Research.*[3]

Figure 13. *Facilities for storing liquid radioactive wastes in the physics building at the University of Illinois.*



Miscellaneous Rooms

Separate rooms are occasionally set aside for such operations as glassblowing, high frequency heating, evaporation of metals and crystal growing. More often the facilities for such operations are assembled in a common general purpose room. The top of a glass blowing bench should be protected by means of a Transite sheet. The tools and accessory equipment and a convenient layout for glass blowing are given in Strong's *Procedures in Experimental Physics.*[4]

Where training in elementary glass-blowing techniques is given in connection with a laboratory course in techniques of experimental research several glass-blowing stations are usually set up. To minimize the number of tanks that must be stocked, oxygen is frequently piped at low pressure to the several stations from a common tank. Whenever tanks are used, however, as is true for all tanks containing gas under high pressure, they should be strapped or otherwise held securely in position so they cannot fall over.

Liquid helium is needed for the low temperature research that is now under way in a large number of physics laboratories. Figure 14 shows the cryostat installed for liquifying helium in the physics building at the University of Illinois.

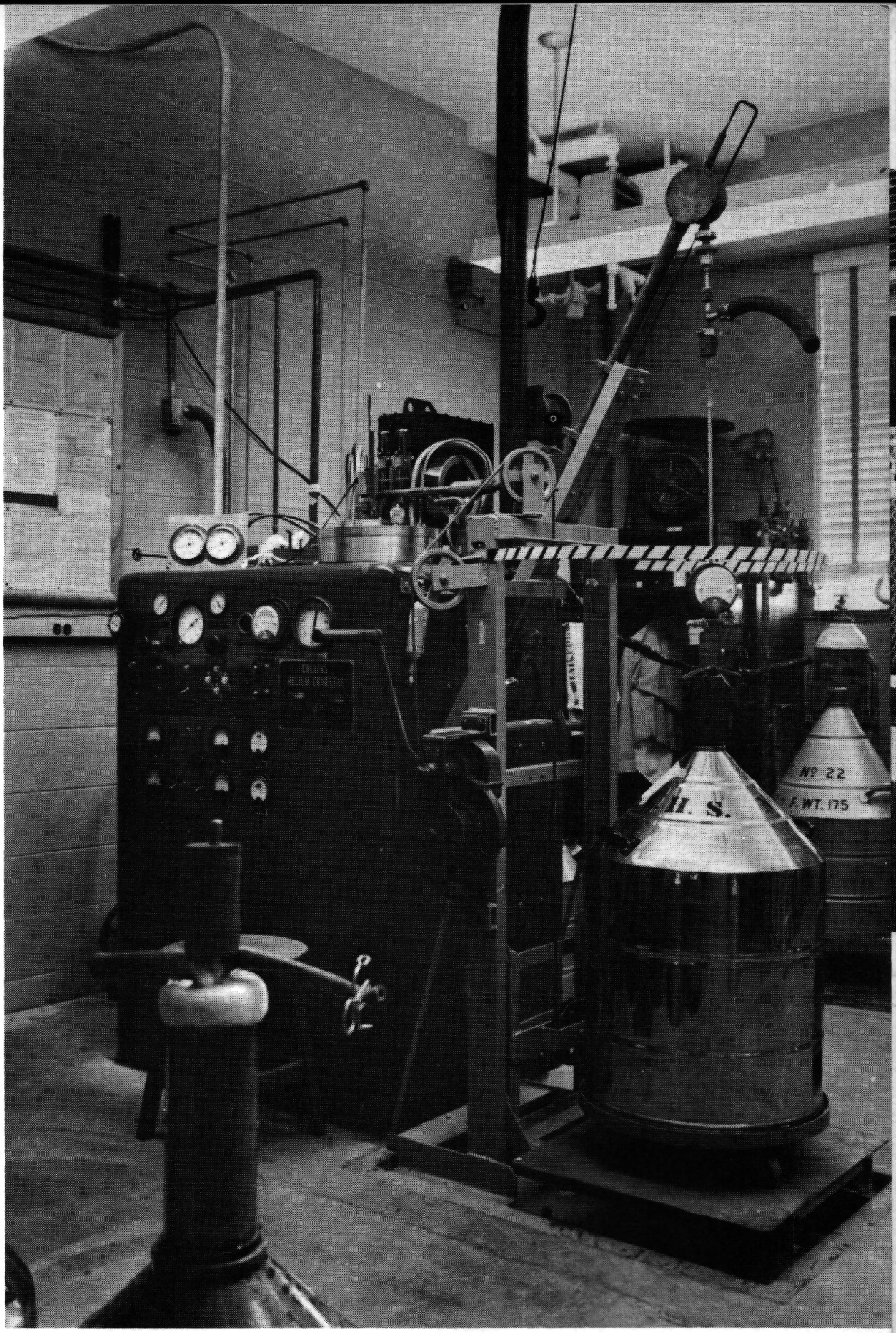


Figure 14. Helium cryostat in the physics building at the University of Illinois.

STORAGE FACILITIES

Lack of adequate storage space has been one of the most frequent complaints we have heard. New buildings have even been found inadequate in this respect as soon as they were occupied. To emphasize the importance of such space, one physicist suggested that in planning a new building one should request at least twice as much space for storage as probably will be required immediately.

A variety of kinds of storage space is required by a department of physics. Space must be provided to store apparatus used in teaching laboratories and in lecture demonstrations (discussed in earlier chapters); materials and instruments used in research; metal and wood stock needed for the shop; and apparatus which has no immediate use but which may find a use at some later date.

Various types and sizes of bins, chests of drawers, cabinets, racks and cases—both open and closed—are required, and sufficient facilities of the types needed should be supplied so that different kinds of things can be kept well separated.

In planning each storeroom, provision should be made for an adequate inventory and for keeping it up to date.

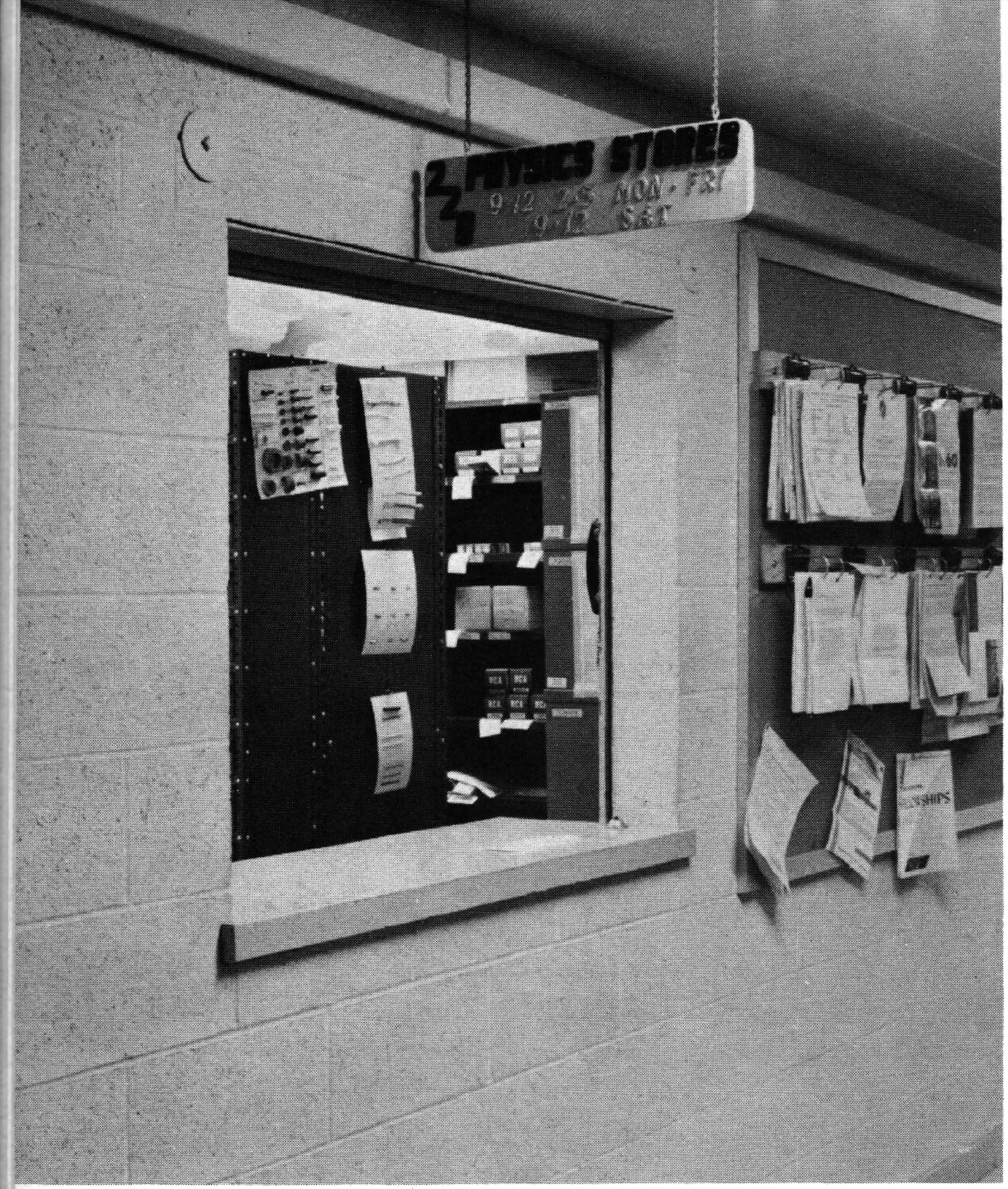


Figure 15. Check-out window of physics store room at the University of Illinois (above); view inside store room (below).

Instrument and Materials Storage

A special room is required for storing the large stock of materials, instruments and incidental items required for research. One or more technicians who have the responsibility of keeping records of the equipment and materials on hand are usually assigned to this room, and more or less formal sign-out procedures are established. Figure 15a shows the check-out window for the Physics Stores in the new physics building at the University of Illinois and 15b a view inside the room. Besides storage cases, shelves, chests of drawers and bins, a workbench and set of tools for making minor repairs should be at the disposal of the storeroom staff. If the storeroom is close to the receiving area, as at the University of Pennsylvania (Figure 2), the staff may also be responsible for the proper distribution of shipments received by the department.

Open shelf storage is convenient for general supplies. Closed cases should be provided for instrument storage. Delicate instruments exposed to dust and fumes deteriorate in operation as well as in appearance.

POTENTIOMETERS
& RHEOSTATS
BATTERIES
— METERS —
— RELAYS —
TUBES

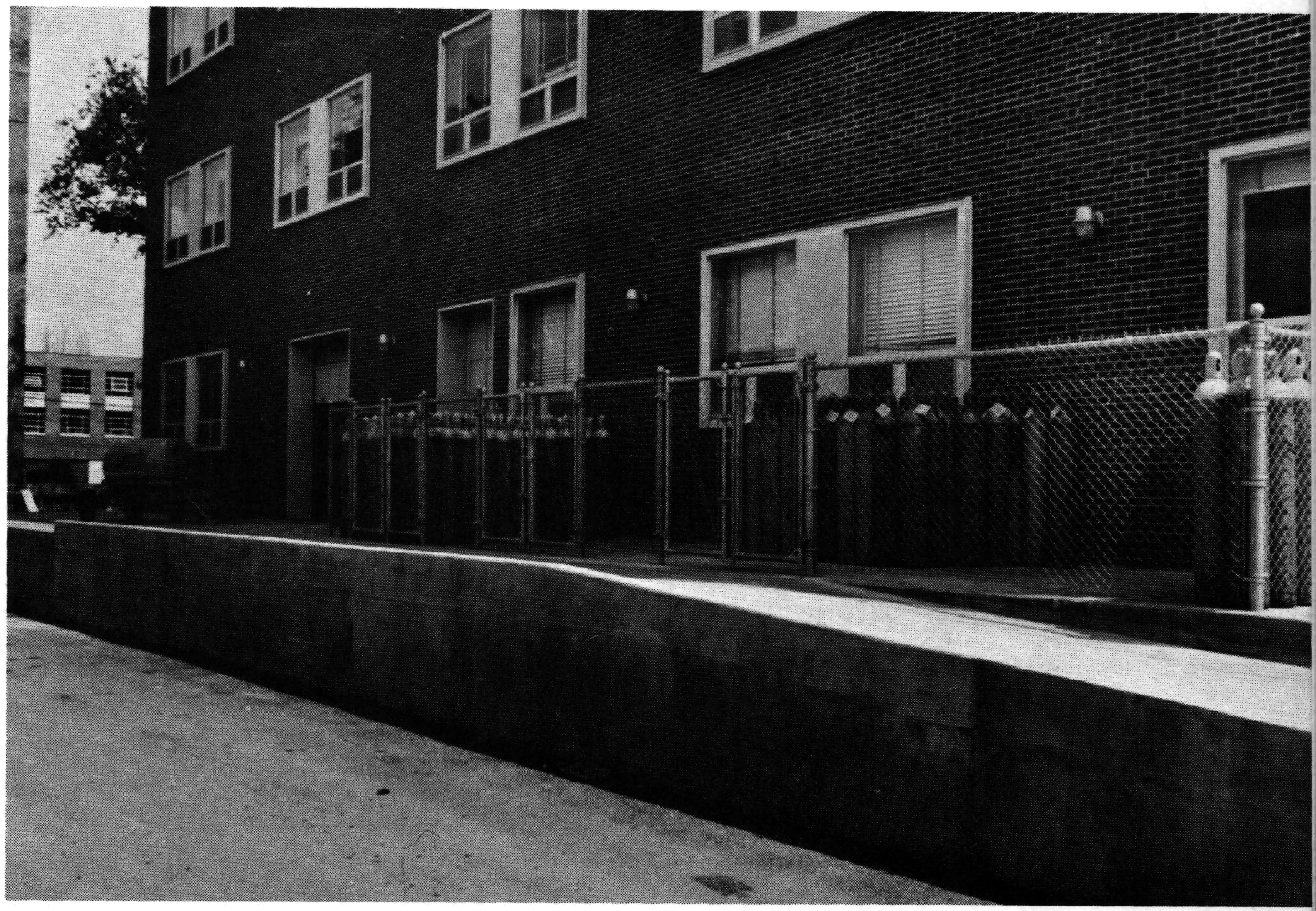


Figure 16. Tanks (mostly helium) are stored on the loading platform of the physics building at the University of Illinois. Note liquid nitrogen tank on wheels at far end of platform.

Storage of Raw Stock

Every shop needs space for storing the variety of raw materials that must be kept in stock. Separate rooms may be set aside for this or, as is more frequently done in a small department, storage may be within the shop itself. The space that is set aside for storage of stock at some representative institutions appears in a table at the end of this chapter. Commercially available storage devices of various kinds that are made of steel are widely used. However, we have seen many homemade racks built to the specific needs of the local shop—racks which are either free standing or attached to walls. Angle iron which is punched with holes and slots (similar to Dexion) is convenient for this purpose because of its versatility. Such angle stock is available in several weights in both aluminum and steel. It can be assembled easily with bolts and nuts to any desired dimension. A frame of angle iron can be used directly for storing long stock, and plywood boards can be added where continuous shelves are required. Metal channels (similar to Unistrut) are also used for such frames, as in the shop at the University of Florida (Figure 6).

All-Weather Storage

Transformers for the electric power for the building are frequently installed out-of-doors or in a vault below ground adjacent to the building. This has the special advantage that, when power requirements have grown to the point that a larger transformer is required—and this has been the history of most physics buildings—it is relatively simple to make the exchange.

Steel tanks for liquids and gases are also frequently stored out-of-doors. This not only saves space in the building but it may also be desirable for reasons of safety. Figure 16 shows an array of tanks (mostly for helium) on the loading platform at the rear of the physics building at the University of Illinois. The tank on wheels at the far end of the platform is for delivering liquid nitrogen from a commercial supplier. At some institutions a steel-jacketed container for liquid nitrogen is permanently installed out-of-doors. Figure 17 shows a spherical tank for this purpose in the back yard of the Gibbs Laboratory at Yale. An out-of-doors installation of this type is particularly convenient for the commercial supplier to service.

A physics building should have a back yard where a dock, which is bound to be cluttered occasionally, and other unsightly items can be at least partially shielded from public view.

Dead Storage

When a building is first built there is usually plenty of space for storing discarded apparatus which may be used either in whole or in part at some later date. Sub-basement and attic are useful for this purpose. But, as a department grows, other activities encroach upon this space and eventually may reduce it to zero. Spare space in other buildings on the campus is then sought, and it even may be necessary to rent space off the campus for second-class storage as is done by the physics department at Massachusetts Institute of Technology. In any event, in planning a new building, space set aside for second-class storage can easily be justified—both for its immediate use and as space for future expansion.

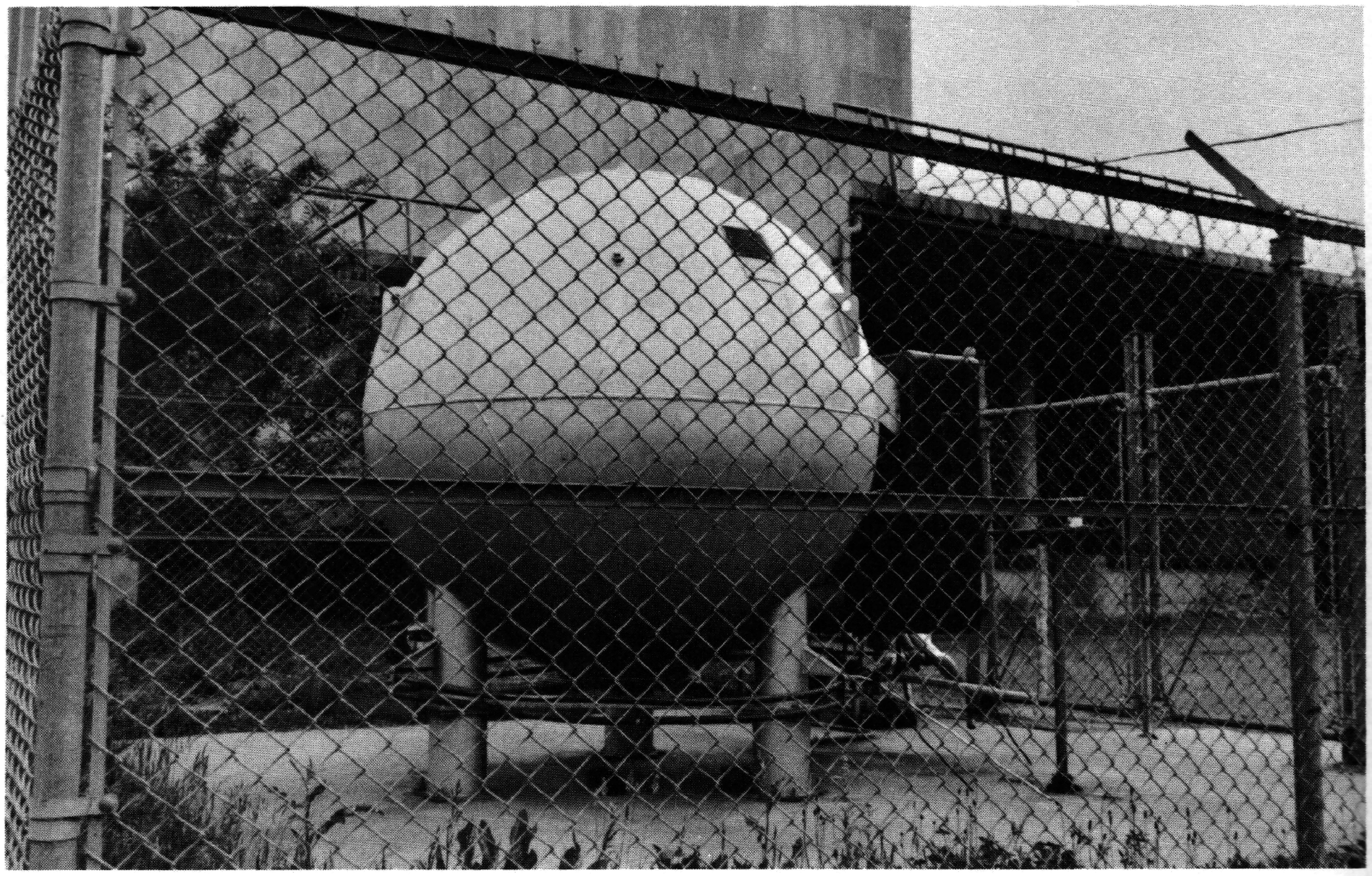


Figure 17. Spherical tank for storing liquid nitrogen out-of-doors at the Gibbs Laboratory at Yale University.

Table I. Shop and Auxiliary Services in the Physics Department at Selected Institutions

Institution	Area, A, in sq. ft. and Number of Technicians, N											
	Machine Shop		Wood Shop		Student Shop		Electronics Shop		Glass Blowing		Fore-man's Office	Stock Storage
	A	N	A	N	A	N	A	N	A	N	A	A
Case Institute of Technology	950	3	—	—	180	—	360	1	—	—	120	215
Duke University	2050* 90%	8	—	—	340	—	400* 60%	1½	500* 60%	1	230	715
Univ. of Illinois	3600	9	450	—	450	—	400	1	—	—	200	2000
Univ. of Florida	1650	5	540	2	360	—	640	3	40	1	120	400
Univ. of Maryland	2800	8	830	—	1040	1	1040	7	1000* 60%	1	—	200
Univ. of Minnesota	2200	15	430	1	560	1	1280	11	1150* ?	?	340	4500
Notre Dame Univ.	340	4	400	—	300	—	1000	2	300	1	125	1200
Oberlin College	3000* 50%	1½	310	—			1000** 50%	½			90	275

* Shops so marked do work for other departments as well as physics.
** This space is shared by Electronics and Glass Blowing Shops.
Percent time assigned to physics is given below each entry, if other than 100%.

Table II. Major Tools in the Student Shop in the Electronics Research Building at the Lawrence Radiation Laboratory in Berkeley

(Area, 920 Square Feet; 1 Machinist Assigned)

5	Machinist Benches
1	Soldering Bench
3	Tool Cabinets
3	Lathes, 15″, 13″, 10″
2	Vertical Milling Machines (Index 45)
1	16″ DoAll Metal Cutting Bandsaw
1	Pedestal Grinder
1	20″ Drill Press
2	16″ Drill Presses
1	6″ Belt Sander
1	Abrasive cut off saw (DIMET)
1	#2 Milling machine
1	Hand Operated Surface Grinder
1	18″ Sheet metal brake
1	18″ Sheet metal shear
1	Rotex Punch
1	10″ Delta Saw and Jointer combination
1	Gas Welding unit.

Table III. Major Tools in the Machine Shop at Millikan Laboratory, Pomona College

(In Order of Priority)

Cincinnati Toolmaster Vertical Mill
Sheldon 14″ Metal Screw Cutting Lathe
Delta Drill presses mounted on drill table
Delta pedestal type grinder
Delta pedestal type reversable tool grinder
  (for carbide tools)
DoAll 31″ throat metal cutting band saw
  (or 13″ Delta metal cutting band saw.)
Gas welding and cutting torches
Birdsell ac Arc Welder
Shopmaster dry belt sander
Monarch 18.5″ Metal Screw Cutting Lathe
Buffalo #18 floor model Drill Press
Diacro sheet metal shear
Diacro sheet metal brake
Diacro sheet metal roller
Wells metal cut-off saw
Diacro rod bender
Grand hydraulic crane and stacker
Marathon pedestal grinder and wire brush
Lisle pedestal type drill grinder
Acme 30 KVA Spot Welder
Levin micro precision drill press
Engelburg wet belt sander
Lapping machine
K. R. Wilson Hydraulic Press
Cincinnati pedestal type buffer and polisher
Micro Engraver
Covel 18″ x 10″ Surface Grinder
Milwaukee #3 Horizontal Mill
Cincinnati Monoset tool and cutter grinder
Diacro sheet metal notcher
Hevi Duty electric oven
Hydro Hone

Table IV. Major Tools for a Shop for Seven Machinists

(List prepared by D. W. Stallings,
Superintendent of the Mechanical Shops at the
Lawrence Radiation Laboratory, Berkeley)

Machine Shop Tools Required (in order of priority)	Area Required (including benches and working space—square feet)
15″ Lathe	60
Gorton or Cincinnati Vertical Milling Machine	64
10″ Lathe	40
Pedestal Grinder	9
36″ DoAll Saw (Metal cutting)	200
20″ Drill Press	12
6″ Belt Sander	9
24″ Diacro Sheet Metal Brake	9
24″ Diacro Shear	9
Rotex Punch	8
Acetylene Torch Unit	6
5 Machinists Benches	125
3′ x 5′ Granite Surface Plate	63
10″ Delta Combination Saw and Jointer	64
Polishing Lathe (Buffer)	24
Soldering Bench	56
Wells cut-off saw	48
6 Ton Arbor Press	6
12″ Drill Press	12
Tool Crib Space	215
Aisle Space	400
#3 Milling Machine	256
8″ x 24″ Surface Grinder	154
20″ Lathe	200
15″ Lathe	60
3′ Radial Drill	200
10″ Lathe	42
Pedestal Grinder	9
40 Ton Hydraulic Press	50
10″ Universal Grinder	120
6″ x 6″ Electric Oven (For heat treating)	4
	TOTAL 2534

10. Offices and Conference Rooms

INTRODUCTION

The function of an office is twofold. It provides a place which a faculty member can call his own—a place for keeping his personal books and journals, for study and for planning his work. It also provides a place for conferences with colleagues and with students. These activities require a certain degree of privacy if they are to be effectively accomplished, whether by a senior member of the staff or by a teaching assistant.

Offices are usually grouped together either in one or several areas of the building. This makes it possible for members of the staff with similar problems and interests to confer more readily with each other. It also simplifies the problem of design and produces economy in construction since offices do not need the extensive services required in other areas in the building.

FACULTY OFFICES

Single versus Multiple Occupancy

According to a questionnaire distributed to about 25 physics departments, 70% of the offices in these departments are one-man offices. The remaining 30% house two or more persons. Hence, about half of the faculty members at these institutions have private offices and the other half must double up.

Sharing of offices is unanimously deplored by those who completed the questionnaire. They stress the need for single offices since they "offer more privacy and less distraction." One reply states that "multiple occupancy is workable only for staff members who spend much time in their laboratories." Nevertheless, multiple occupancy *is* resorted to.

When new buildings are built, single offices normally are provided all members of the faculty. But as the department grows it becomes necessary to double up and, as expressed by one respondent, the formula used becomes "single offices for professors and associate professors; two to an office for the remainder." Though "single offices are much more desirable, (it becomes necessary to) make do with what we have." The need for conserving space in planning a new building is also recognized. As expressed by another, "double offices are not as satisfactory to the staff but they enabled us to have more research space."

Where multiple occupancy has been required, tall bookcases between desks have helped to produce a sense of privacy—giving at least some protection from visual distractions even if acoustical distractions remain.

Office Size

The offices for single occupancy reported range in size from 80 square feet up to 300 square feet with a median at 160 square feet. The size of the double offices reported averages 210 square feet. A perusal of the building plans of Chapter 4 indicates that the mean size of the offices in these buildings is also in the neighborhood of 160 square feet.

Where quite small single offices are available, they are normally assigned to persons with short-term appointments—visiting professors and post-graduate fellows, persons who do not require space for a large personal library and who do not have the responsibility of student conferences.

One might think that theoretical physicists would be supplied larger offices than experimentalists. Having no laboratory, the theoretician spends more time in his office and might well require more space—more chalk board space and more space for conferences. However, only a few departments attempt to make such a distinction, not enough to make a significant difference in the average size of the offices reported.

Office Equipment

Besides the conventional furniture—desk and swivel chair, filing cabinet, bookcase, coatrack and visitors' chairs—physicists stress the need for a work table and a chalkboard in each office. We have seen a few offices in which a laboratory work bench equipped with electrical and mechanical services has also been provided. Such an installation may be useful for an experimental physicist. It not only provides additional space for research but also enables him to work on problems (which may or may not be related to his principal research activity) with less interruption than would occur in his main research laboratory where graduate students and research assistants are at work. The office-laboratory is, of course, not a satisfactory substitute for well-equipped research space. Occasionally, though quite rarely for physics departments, an office is provided with a side room equipped as a private laboratory. This is done for each of the four offices at Pomona College (Figure 1). Private laboratories adjacent to faculty offices are more often found in chemistry buildings than in physics buildings.

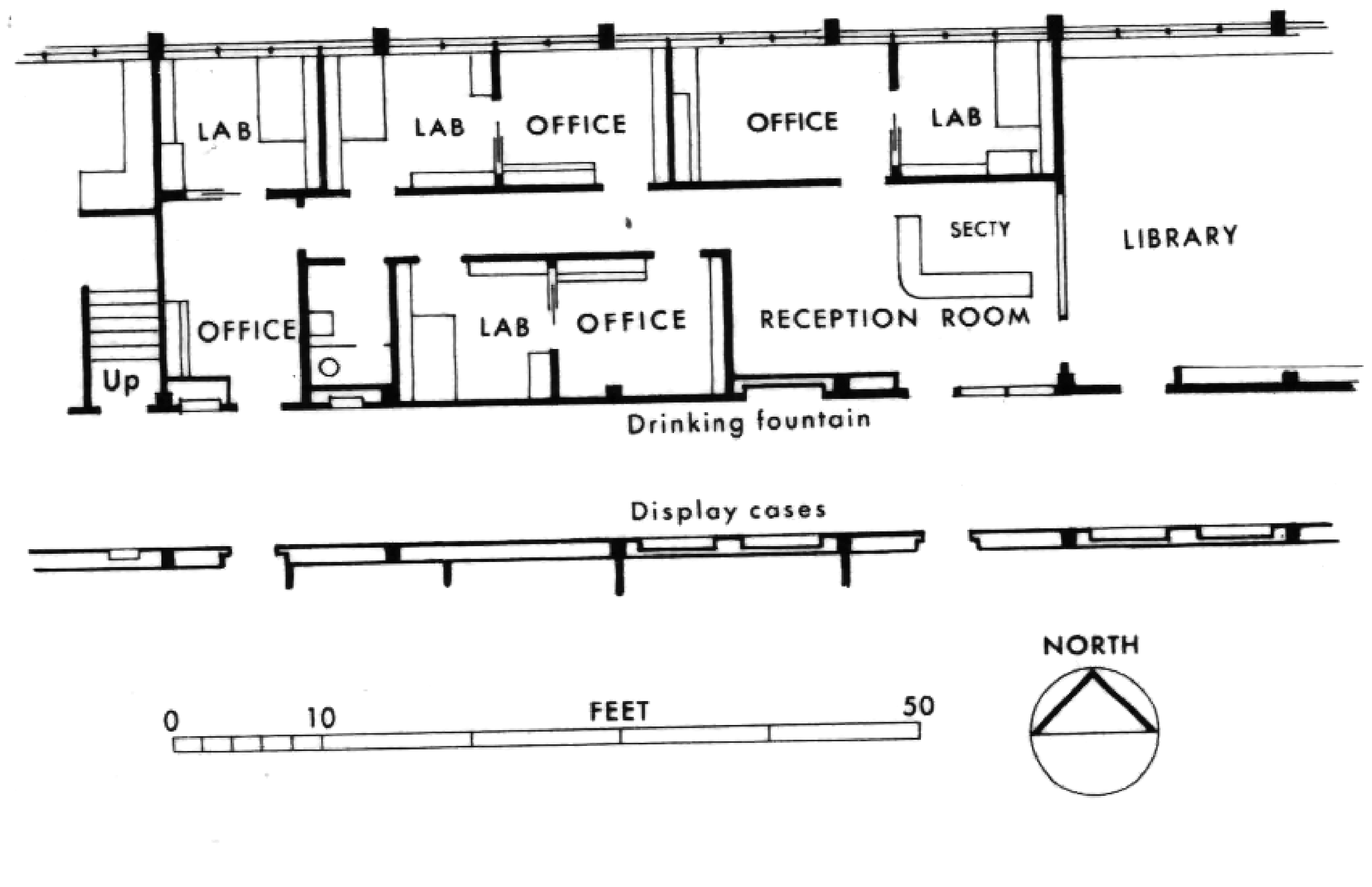


Figure 1. Floor plans of the office suite in the Millikan Laboratory at Pomona College (Chapter 4, Figure 11). A private research laboratory is associated with each office.

Office Arrangement

Most persons want windows in their offices. They like to be able to look outdoors—possibly simply to rest their eyes; at other times to determine the state of the weather. The desire for windows poses problems which affect the design of the building. Matters would be considerably simplified for the architect if windows were not required, and there are some signs that the trend is in this direction. We talked with several persons who have interior offices in buildings we visited and heard few objections to the lack of windows. Two of the four offices at Pomona are interior offices. All the offices in the educational buildings at the Air Force Academy are interior offices. The physics staff at the Academy indicated satisfaction with the arrangement. All the offices in the new IBM Research Center will be interior offices. (See Figure 27 in Chapter 4.) However, the out-of-doors will be visible through large glass areas at the ends of each office corridor. An interior office can be acceptable if it is well lighted, adequately ventilated, and pleasantly decorated.

When the corridor of a rectangular physics building runs down the center of the building, care must be taken lest offices along the corridor be too long and narrow if they are

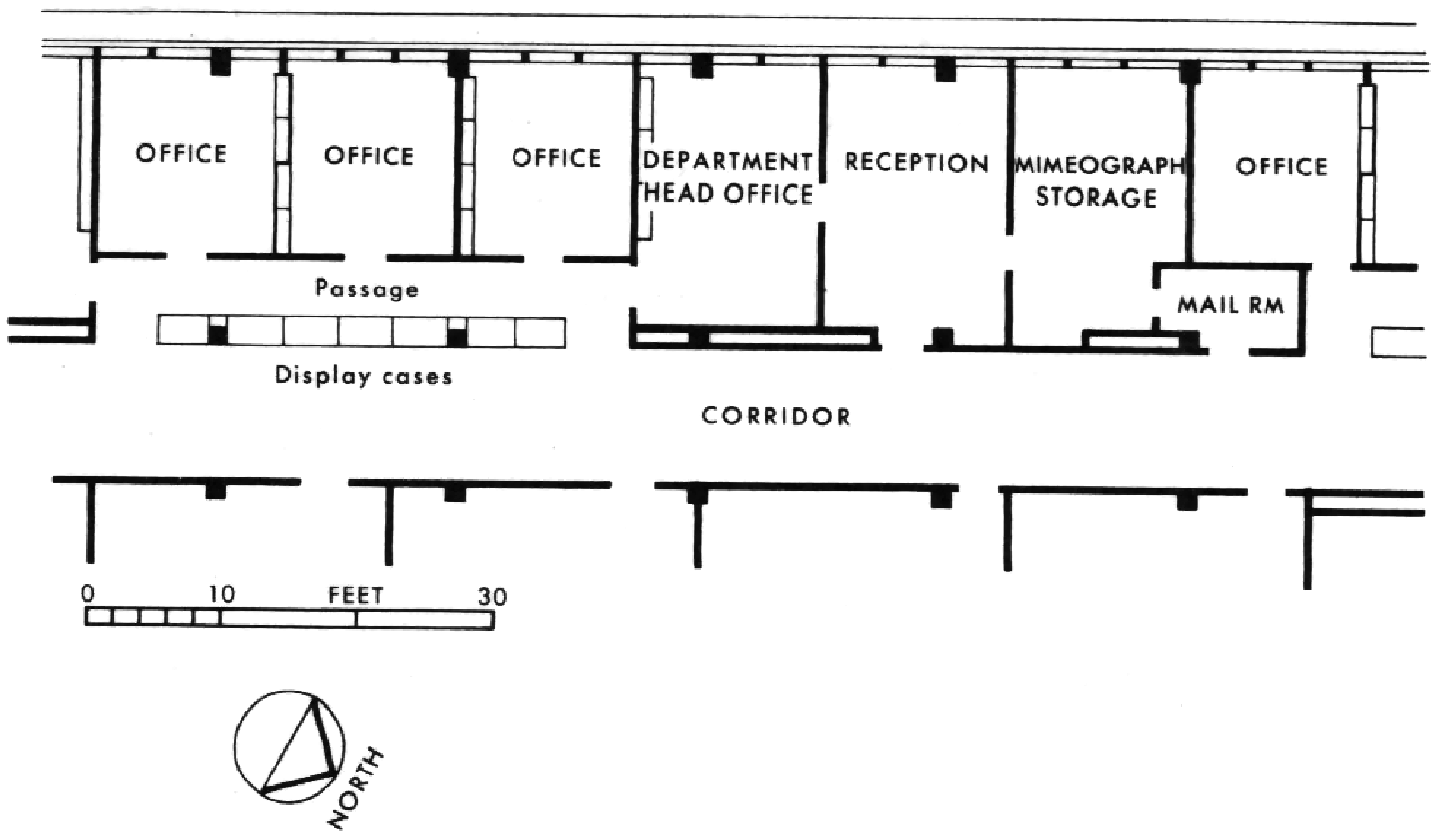


Figure 2. Floor plan of an office area at the University of Florida (Chapter 4, Figure 3), showing subsidiary passageway created by ceiling-height display cases.

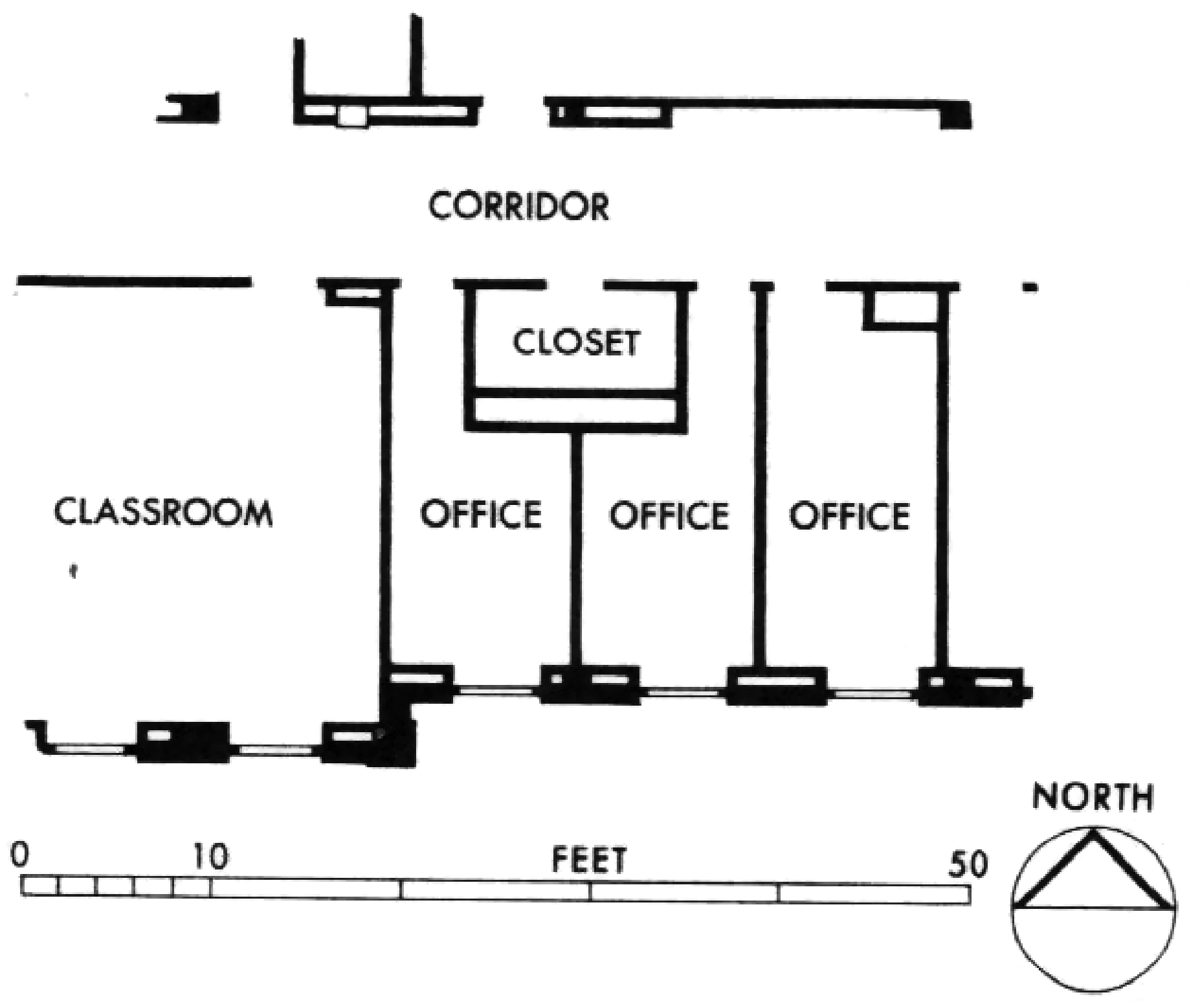


Figure 3. Floor plan of office area in the new physics building at Worcester Polytechnic Institute. Closet off center corridor shortens length of offices.

held to the desired size. An office of about 160 square feet in area can well be 16 by 10 feet in dimension, or possibly 18 by 9 feet; but if the office is much narrower it becomes difficult to arrange furniture for the efficient use of the room.

To meet this problem, a rectangular building is frequently designed with an off-center corridor as in the physics building at Illinois Institute of Technology. (See Chapter 4, Figure 21.) A 15 to 18 foot dimension on the narrow side of the corridor is not only satisfactory for offices; small classrooms, seminar rooms, conference rooms, storerooms, and stairwells can also be fitted into this space.

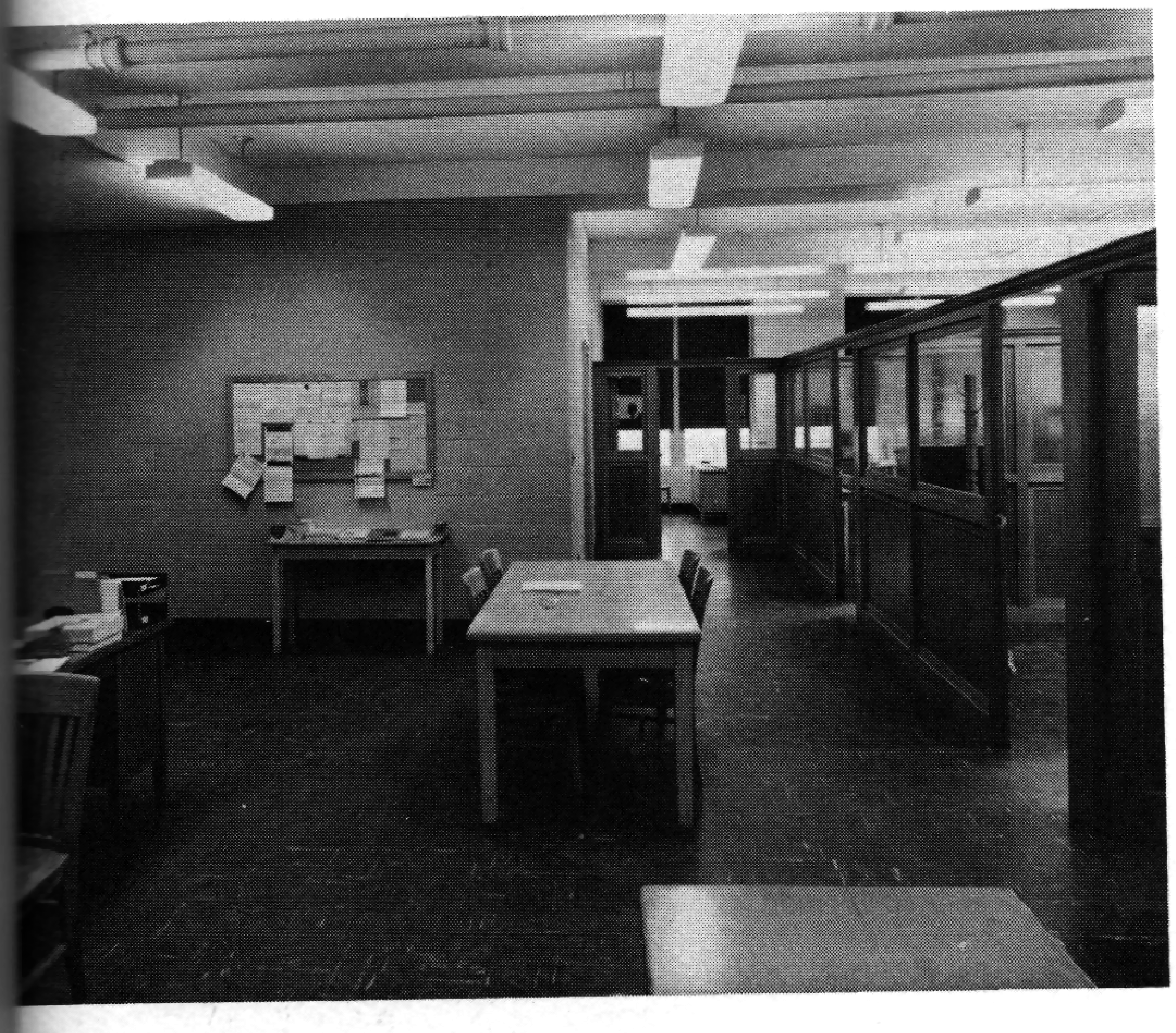
The problem of providing offices of the desired shape and size in a building with a center corridor is met in the new physics building at the University of Florida by the use of subsidiary passageways (Figure 2). Each of the two passageways serves three offices and is created by a ceiling-high display case, 32 feet long by 2 feet deep, which separates the passageway from the main corridor. Offices are then only 14 feet deep (by 13 feet wide), whereas they would be 20 feet deep if they extended to the corridor. This scheme not only yields offices of the desired size and shape but also offices which are somewhat quieter. Corridor noise will be less evident than when office doors open directly onto the corridor. In addition, the display cases themselves can be used for a variety of valuable displays. Changes in displays are made through doors which are located on the passageway side of the cases. See the entire floor plan of the Florida building in Chapter 4, Figure 3.

Figure 3 shows the method used to limit two offices to the desired size and at the same time gain an additional room in the new physics building at Worcester Polytechnic Institute. A small storeroom is taken out of the corridor side of each office leaving a narrow entry at the doorway to each office. The storerooms are variously assigned such functions as the storage of office supplies and the housing of laboratory standards. See Chapter 4, Figure 15 for the complete Worcester floor plan.

One method of obtaining offices of the desired size and at the same time providing each office with a window is to design a wing especially for offices. This is the plan adopted for the new Physics-Engineering Building at The Cooper Union (see Chapter 3, Figure 1). The dimensions which offices must take are normally circumscribed by the building module that is adopted. When a wing is specially designed for offices, this procedure can be reversed. The module for the office wing can be selected to provide the desired office dimensions. Certain economies of construction are also obtained by the use of an office wing. Since the traffic in this area will be light, corridors can be narrower. Furthermore, the distribution of electrical and mechanical services does not need to be as extensive as in the rest of the building.

A large open area can be divided into offices by means of low partitions as in the new Graduate Center Building at Northeastern University, (Figure 4). Low partitions are particularly convenient from the point of view of flexibility; changes in the number and size of offices can more readily be made than when the more permanent ceiling height partitions are installed. Offices in such an area are more open and airy and thus provide a better circulation of air. If offices are small, they seem less separated from the out-of-doors. Low partitions can also be cheaper to install than ceiling-height partitions. In an area with a high ceiling it would be necessary to provide a separate furred ceiling in each office if the rooms are to be dimensionally acceptable. The significant objection to the permanent installation of low partitions in an office area is the resulting lack of the privacy so urgently desired by most instructors.

Figure 4. View of physics office suite in the Graduate Center Building at Northeastern University, showing use of low partitions.



The new physics building at the University of Illinois is a massive structure. However, it has been designed with laboratories, storerooms, and other rooms within the heart of the building so that the offices can be on the outer walls and thus have windows, as shown in the floor plans, Chapter 4, Figure 6. Notice that rooms such as toilets and service shafts, which require no windows, are placed adjacent to the wall onto which the second phase of construction will be built.

THE DEPARTMENTAL OFFICE

The departmental office for a physics building is usually centrally located and on a lower floor, frequently off the main lobby, for the convenience of students and others who may have business with the department. Where it is not so located, directions for reaching it should be prominently displayed at each entrance to the building.

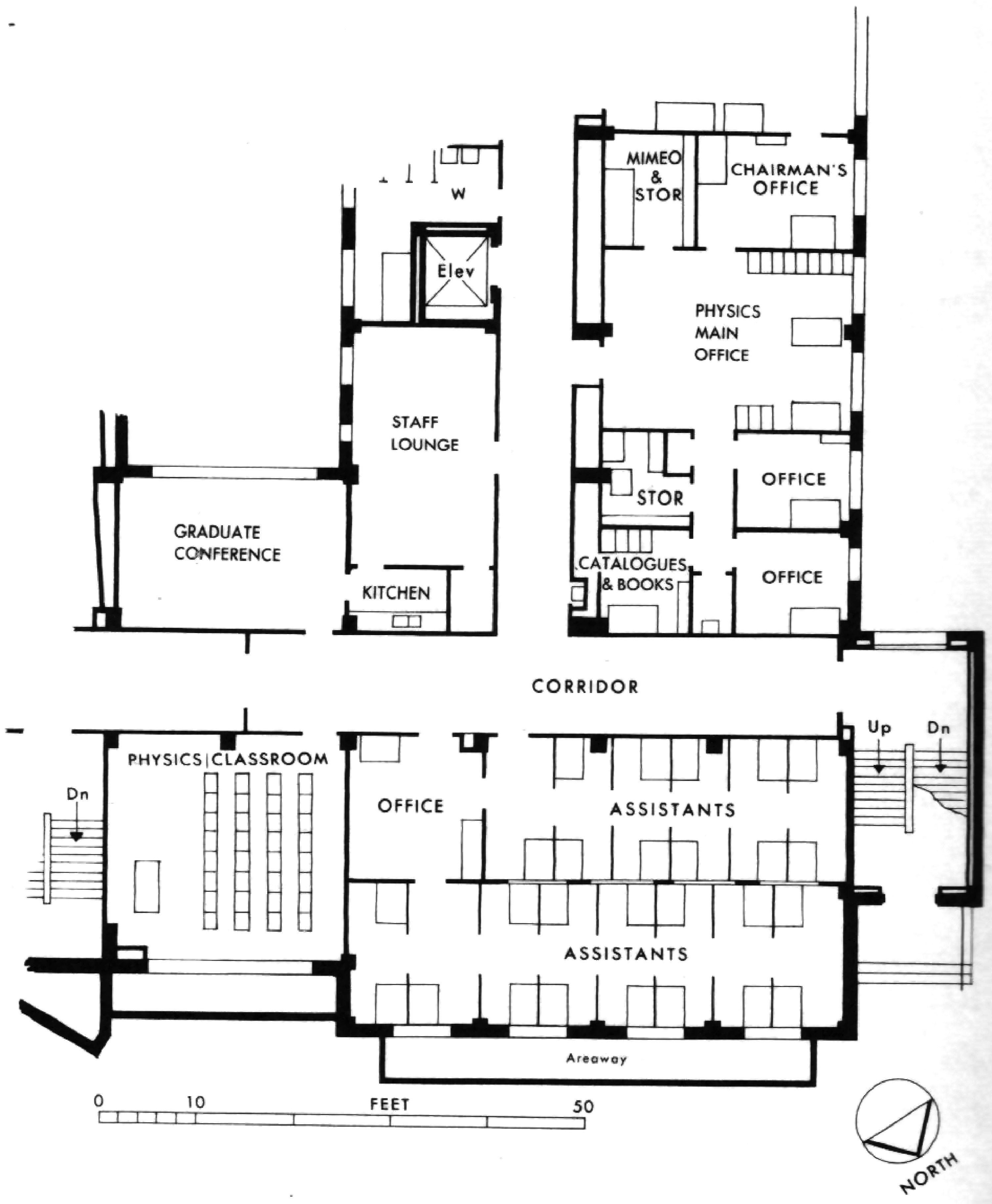
The size of the department determines the extent of the services performed by the departmental office and therefore the space required. The departmental office will frequently consist of a suite of rooms—a reception room, duplicating room, mail room, storeroom for records, and an office for the chairman of the department. A large department may have an administrative assistant or a business manager, and his office may well be a part of the departmental suite or in its vicinity, as at the University of Illinois, (Chapter 4, Figure 6). In a small department, on the other hand, the chairman's office *is* the departmental office, and duplicating and other services are provided by secretarial help in either a divisional or an all-college office.

The physics departmental office at the University of Florida lies between these extremes in size. As shown in Figure 2 it consists of a reception room, about 20 by 13 feet; a room about the same size on each side of the reception room, one for the chairman of the department and the other for clerical services and records; and a small mail room.

The mailroom opens into the services room, and also into the main corridor. The chairman's office has a private door which opens onto the passageway described earlier, in addition to the door to the reception room. A second door for a chairman's office is generally considered desirable. It enables him to go and come more freely without having to pass through the reception room.

Four faculty offices are grouped around the office of the departmental secretary at Pomona College (Figure 1). Besides a reception room, this suite of rooms provides offices and private research laboratories for each member of the physics staff, and a faculty toilet. Since the library is next door to the reception room, with a door and window between the two rooms, the departmental secretary is able to perform double duty as librarian.

Each member of the physics staff should have a mail box and it should be large enough to take small packages, such as books, which arrive by mail. Figure 5 shows the corridor side of the array of generous size mailboxes provided for the staff in the new physics building at the University of Illinois.


W
Elev
MIMEO & STOR
CHAIRMAN'S OFFICE
PHYSICS MAIN OFFICE
STAFF LOUNGE
OFFICE
STOR
OFFICE
CATALOGUES & BOOKS
GRADUATE CONFERENCE
KITCHEN
CORRIDOR
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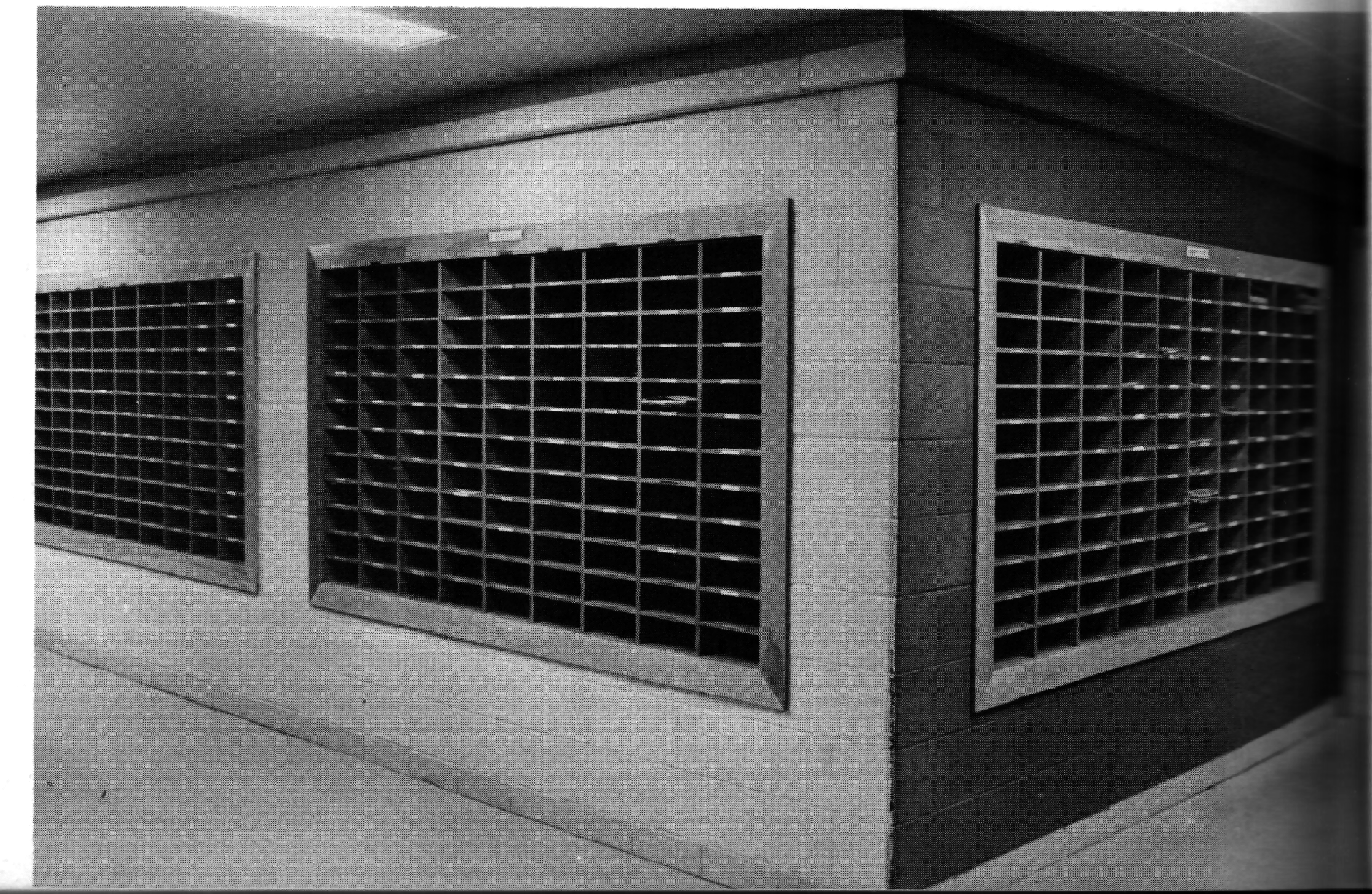
NORTH

Figure 5. Mail boxes for the staff in the new Physics Building at the University of Illinois.



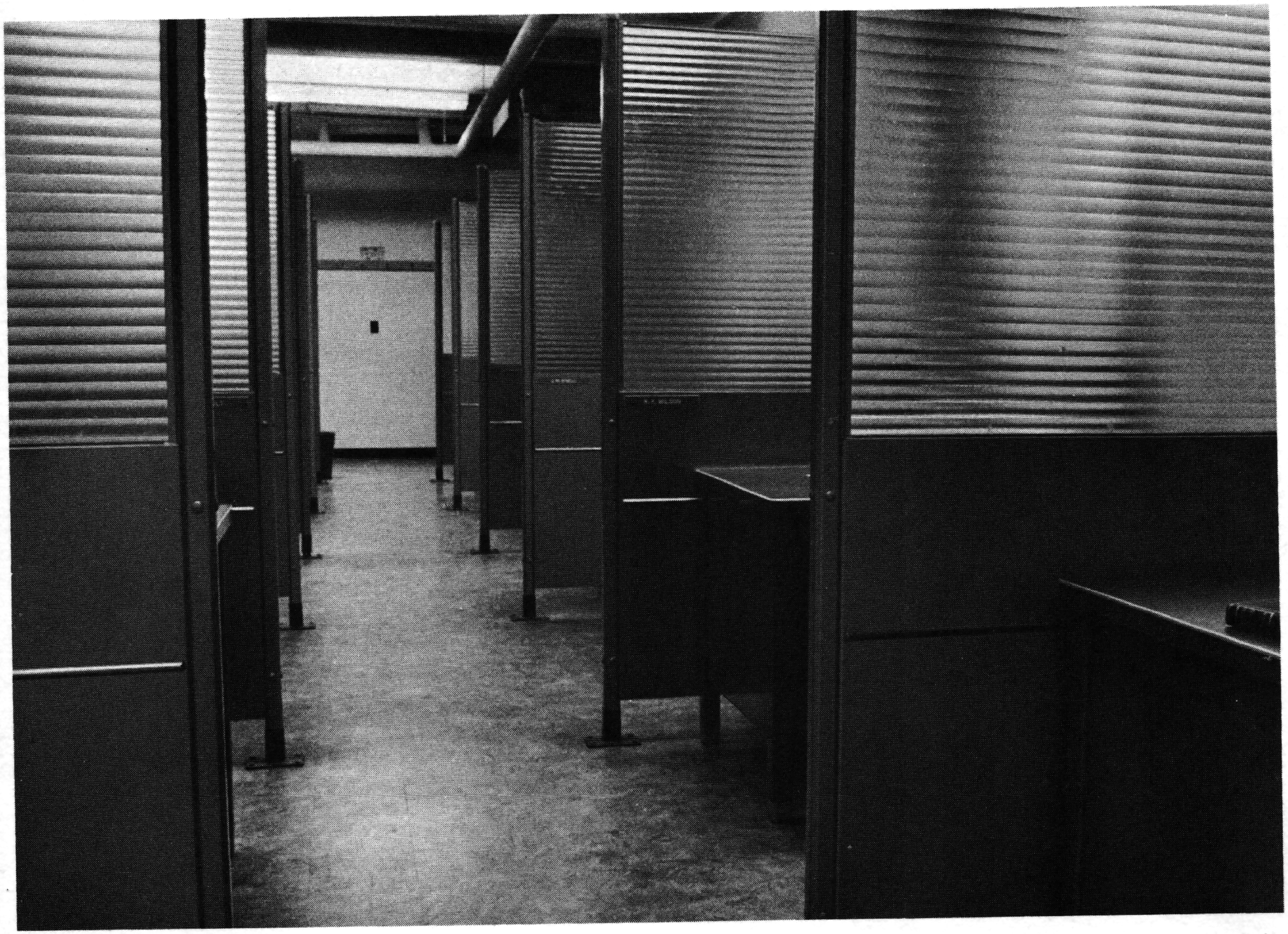


Figure 6. Office cubicles for teaching assistants, University of Kansas (Chapter 4, Figure 23). Floor plan of main office area is shown on facing page.

GRADUATE STUDENT OFFICES

Graduate students who are teaching assistants are normally provided office space, but they must usually double up; quite commonly as many as five or six of them occupy a room that would normally be considered a one-man office at the higher ranks. More often a larger room is used to house a correspondingly larger number of assistants. At one institution there are two offices of 700 square feet each to accommodate about 40 assistants. Needless to say, this crowding is quite generally deplored, for student assistants then have no privacy, either for their own study or for the conferences which are occasionally required.

A much more satisfactory arrangement has been set up by the physics department at the University of Kansas where an office area has been specially designed for teaching assistants. The area has been subdivided into cubicles as shown in Figure 6 so that each of 26 assistants has a desk and a bookcase in a small area which he can call his own. Greater privacy is maintained in the cubicle area by the provision of an outer office where the assistants take turns answering questions of students seeking help.

Graduate students who are research assistants usually have no office other than a desk in the laboratory where their experimental work is under way. Other graduate students, especially those on fellowships and scholarships, are provided desk space when it is possible to do so.

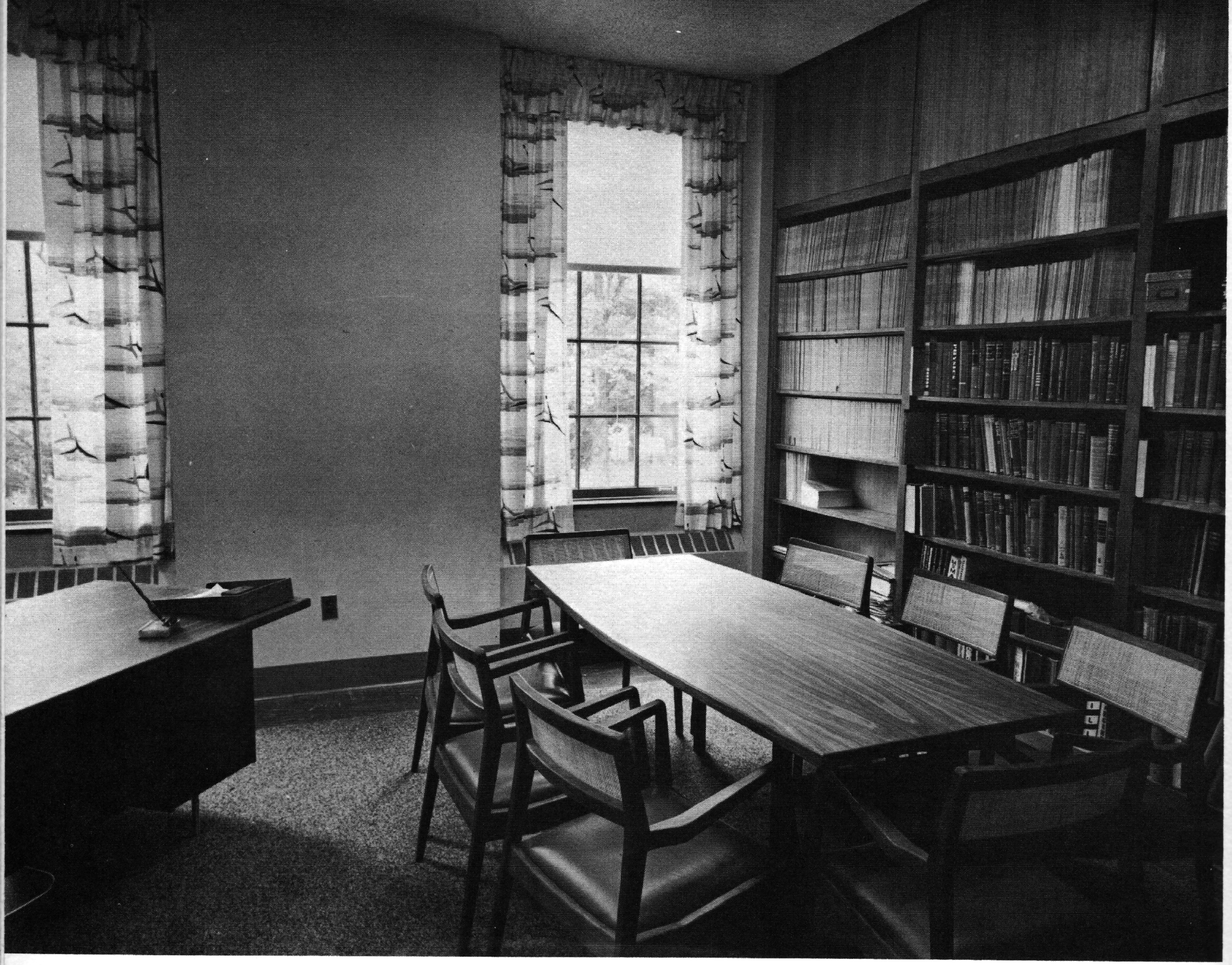


Figure 7. Office of the chairman of the physics department at Worcester Polytechnic Institute.

CONFERENCE ROOMS

If the office of the chairman of the department is large enough, the room is frequently furnished with a long table and several additional chairs for the purpose of holding small conferences. Figure 7 shows such an arrangement in the office of the Chairman at Worcester Polytechnic Institute.

More often a separate room is set aside as a conference room. It is furnished with one or more tables and comfortable chairs as shown in Figure 8 for the conference room in the Physics Building at the University of Virginia. A chalkboard is of course indispensable for such a room. Occasionally a screen for projecting slides is required. A conference room not only serves for formal and informal conferences. It is also used for small classes, staff meetings, oral examinations for graduate degrees, and teas.

A conference room is usually provided modest facilities for the preparation of refreshments. Note the small kitchen adjacent to the conference room at the University of Kansas (Figure 6).

Graduate students are sometimes provided a conference and social room for their own use, as is done at the University of Kansas (Figure 6). The room at Kansas is conveniently located across the corridor from the office suite for teaching assistants. Furthermore, the kitchen which serves the main conference room lies between the two conference rooms and is therefore available to each room.

Conference rooms should be pleasantly furnished. The fine appointments in the conference room in the physics addition at Case Institute of Technology are shown in the photograph of Figure 9.

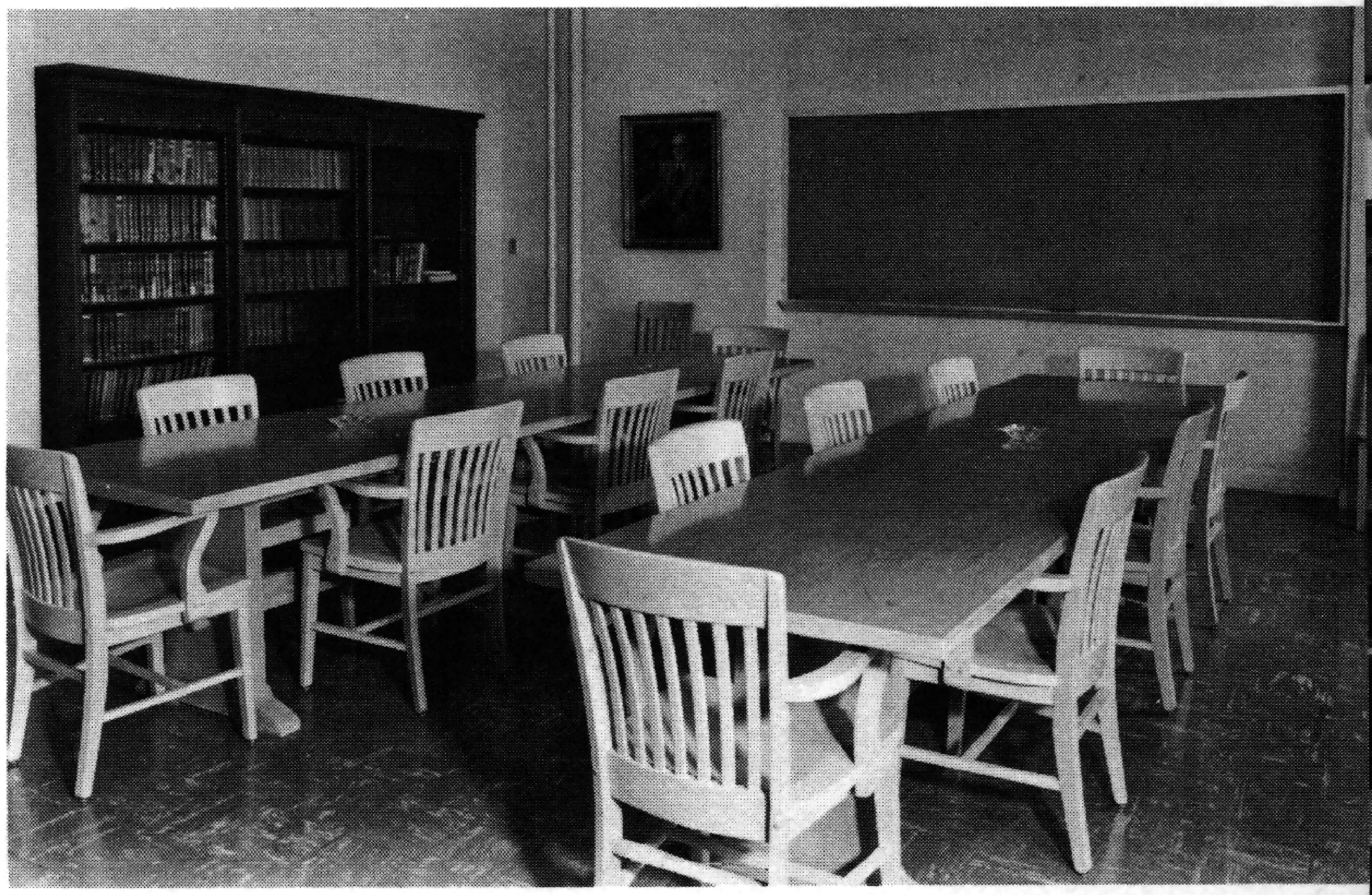
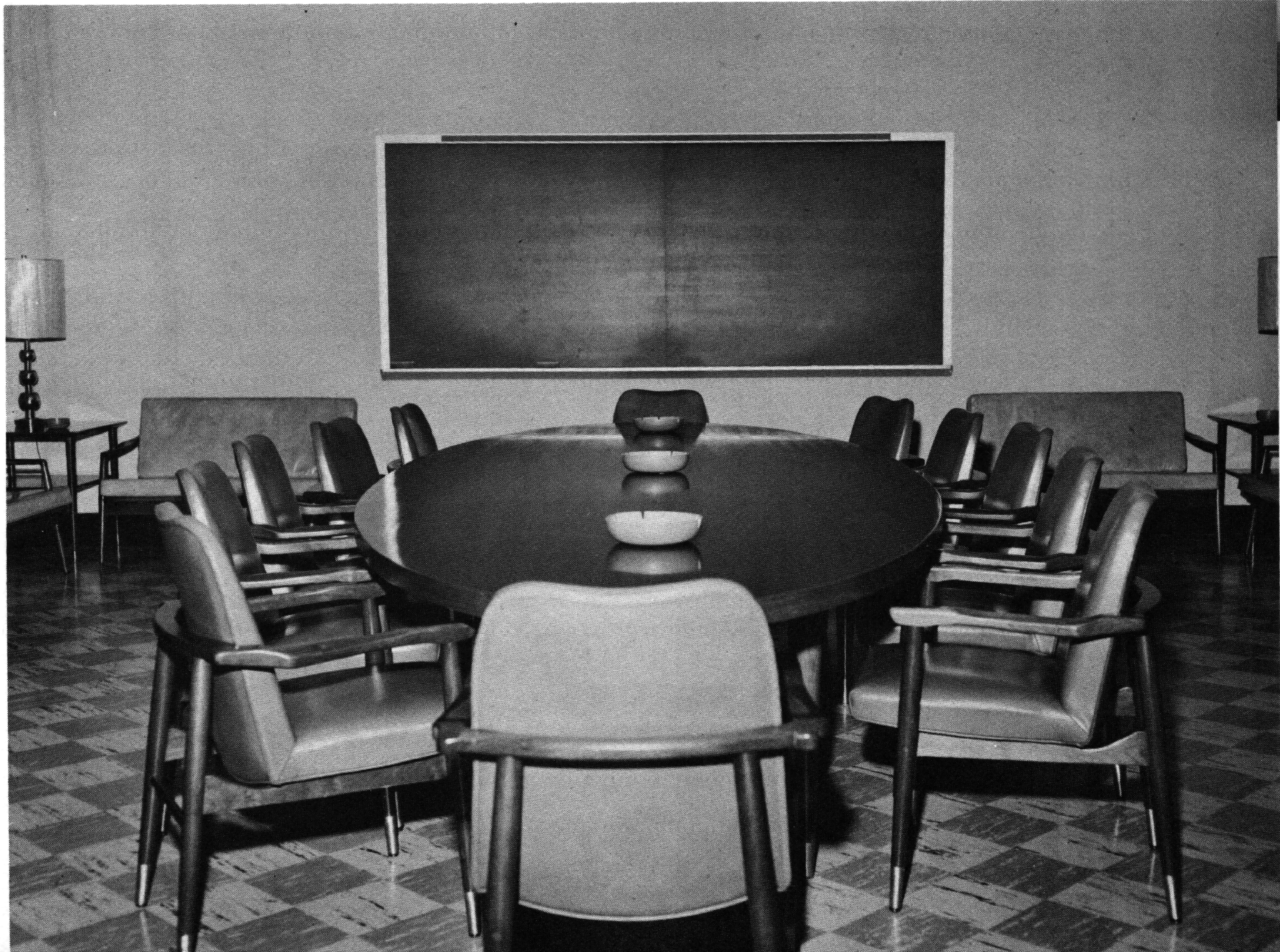


Figure 8. Conference room in the new Physics Building at the University of Virginia.

Figure 9. Conference room in the new addition to the Physics Building at Case Institute of Technology.



11. The Library

INTRODUCTION

Need for Separate Departmental Library

Convenience of location of the physics library is almost as important to physicists as the size and up-to-dateness of the collection. If a department of physics is large enough to have its own building, the department invariably has its own library. If it shares a building with another science or with mathematics, there usually is a joint library, and both departments tend to enjoy a broader library service. If mathematics or chemistry are in an adjacent building, both departments may still share a common library with physics, and all will profit, even though the library may not be as immediately accessible to each. At the University of Maryland, a library serving physics, mathematics and engineering is located in the adjacent mathematics building, and is reached by way of a covered passageway. The library in the new duPont Physical Science Building at Swarthmore which houses the departments of physics, chemistry, and mathematics, is located in a separate wing of the building and serves not only these departments but also the department of engineering (Figure 1).

At institutions where the physics books are located in a central all-university library, the department usually finds it necessary to maintain a small stock of reference books and current journals in some convenient place within the physics building—frequently the seminar room. This is found to be imperative by departments which stress research and the use of the library in their teaching.

THE PHYSICS LIBRARY

Location

We found no preferred location for a departmental library—other than that it be located within the physics building. Some prefer that it be central to all activities of the department. In the new 4-floor (plus basement) physics building at Illinois (Chapter 4, Figure 6) the library is on the second floor and immediately accessible from the stairs at each end of the building. At other institutions the library is located in an area that will discourage undergraduates from using the library simply as a study hall. At the University of Kansas (Chapter 4, Figure 23) the library is on the top floor.

Small departments which do not have a professional staff in their departmental library frequently place the library adjacent to the departmental office. The secretary for the department can then exercise a degree of control over its use. This has been done, for example, in the new buildings at Pomona College (Chapter 4, Figure 11) and at Worcester Polytechnic Institute (Chapter 4, Figure 15).

In any event, the library should be so located that external building noises will be at a minimum. It should be dry and free of fumes from laboratories. Furthermore, its location should be such that it can expand without having to be relocated. Expansion can be readily accomplished if, for instance, the library can absorb the space of a classroom next door; classrooms can be moved more readily than most other physics facilities.

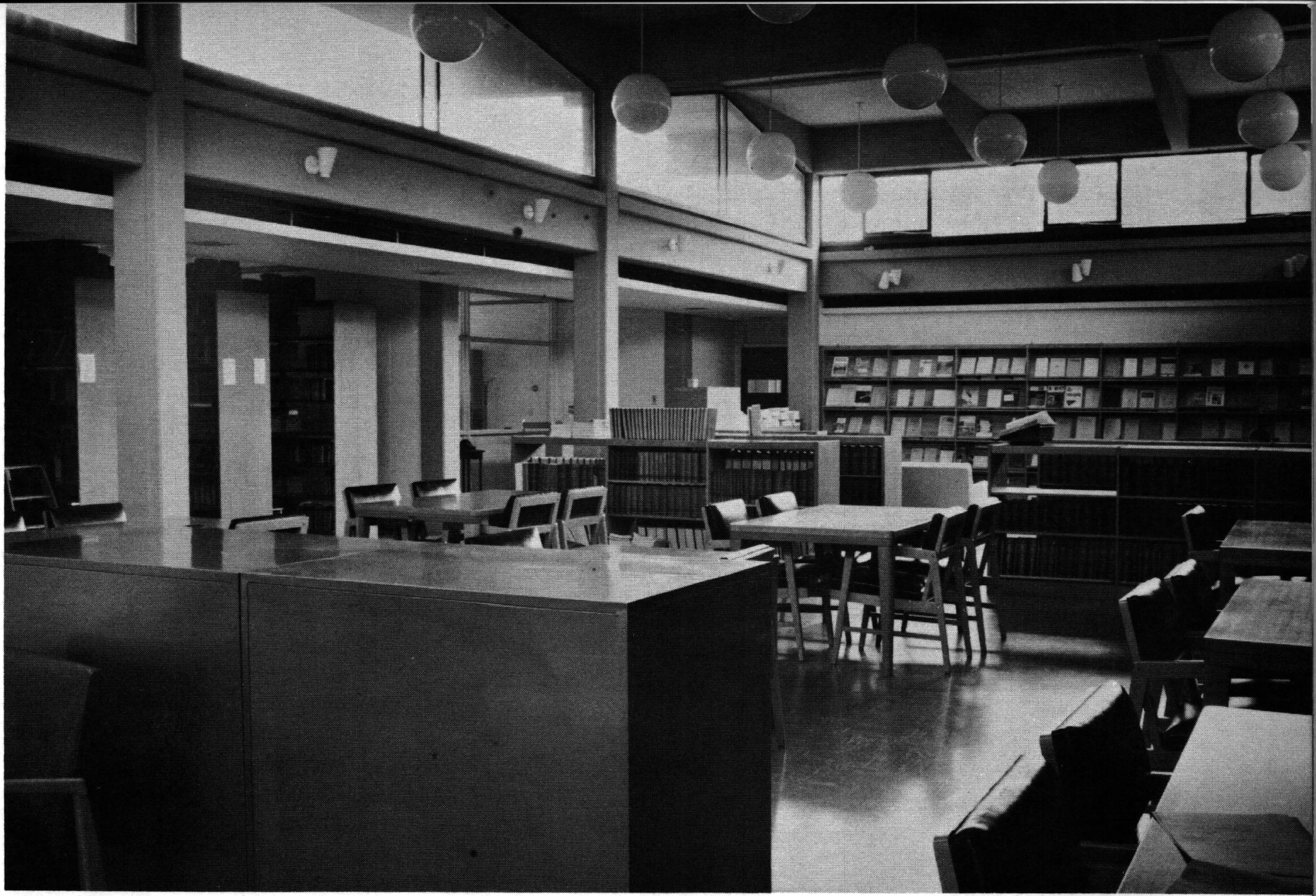


Figure 1. Library in the new duPont Physical Science Building at Swarthmore College serves the physics, chemistry, mathematics, and engineering departments.

Facilities Required

Most well planned libraries provide such facilities as the following:

1. stacks for books, bound journals, and abstracts
2. shelf and display space for recent and current journals
3. display space for new books
4. reading area equipped with tables and chairs, plus the equivalent of a few carrels among the stacks
5. lounge area furnished with upholstered chairs
6. service area to accommodate:
    - *a.* check-out desk or counter
    - *b.* reserve book shelf
    - *c.* card index
    - *d.* reference books
7. workroom and office for professional library staff
8. microcard and microfilm storage and reading facilities
9. files for reports, theses, pamphlets and bulletins
10. vault for classified material and irreplaceable items
11. storage for rarely used books and documents
12. small conference room where conversation is permitted
13. tackboard for temporary notices
14. coat racks

A library for a small department may contain only stacks for books and bound journals, racks for current journals, and a reading area. Other library facilities and professional library services will be provided by the main all-college library.

Space Required

If the physics library, or a joint library with mathematics or one of the other sciences, is to be located in a new physics building, adequate space must be set aside not only to take care of present needs but to allow for an anticipated increase in both the number of books and journals to be housed and the number of people to be served. The space required depends so much on local requirements that it is impossible to prescribe standards.

However, to give some idea of the space that may be required, we will describe the libraries that have recently been provided for three different sized departments. These libraries are at Worcester Polytechnic Institute (Figure 2), the University of Virginia (Figure 3) and the University of Illinois (Figure 4). Each is located in a recently constructed physics building. The floor plans for these buildings are given in Chapter 4.

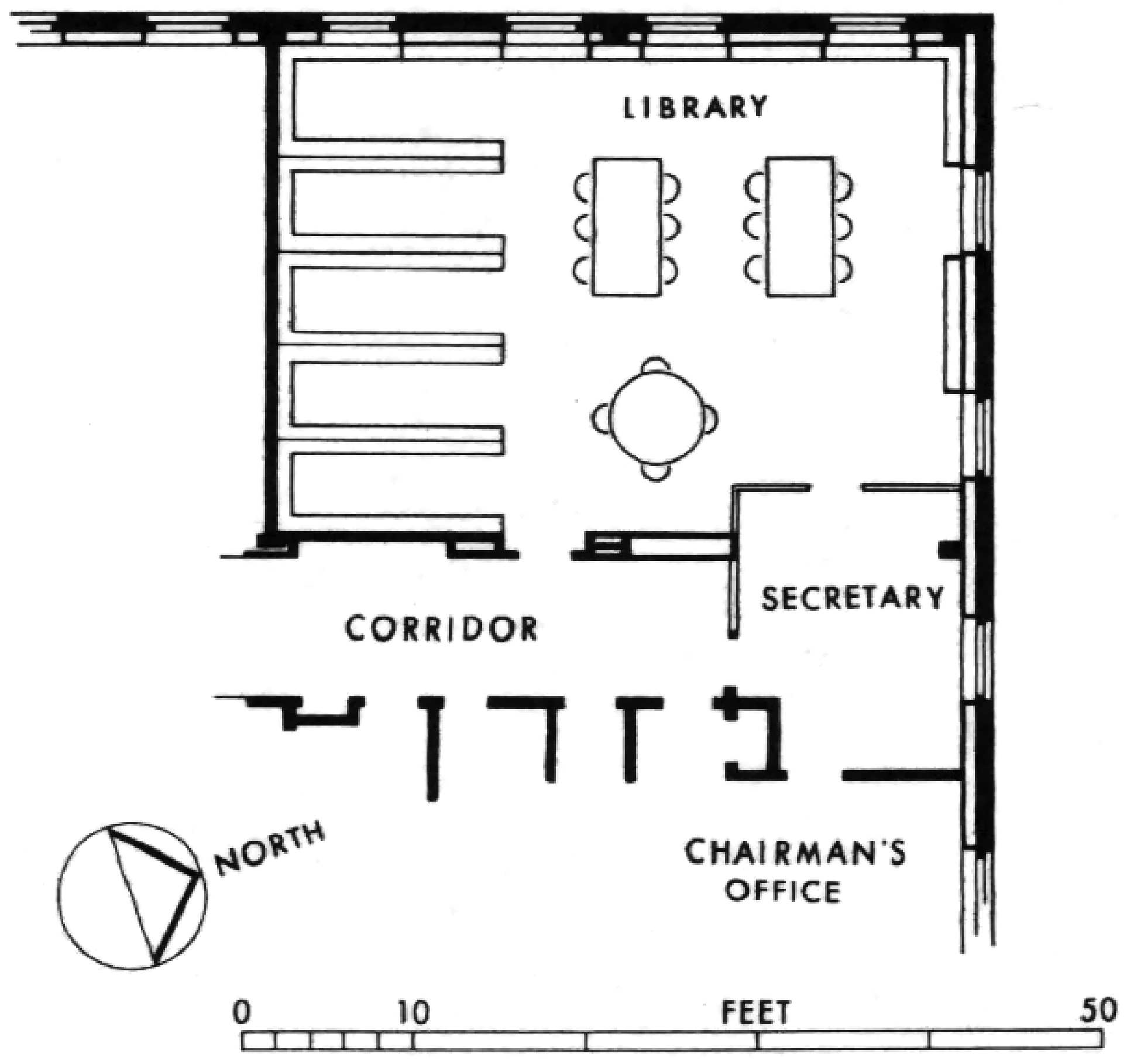
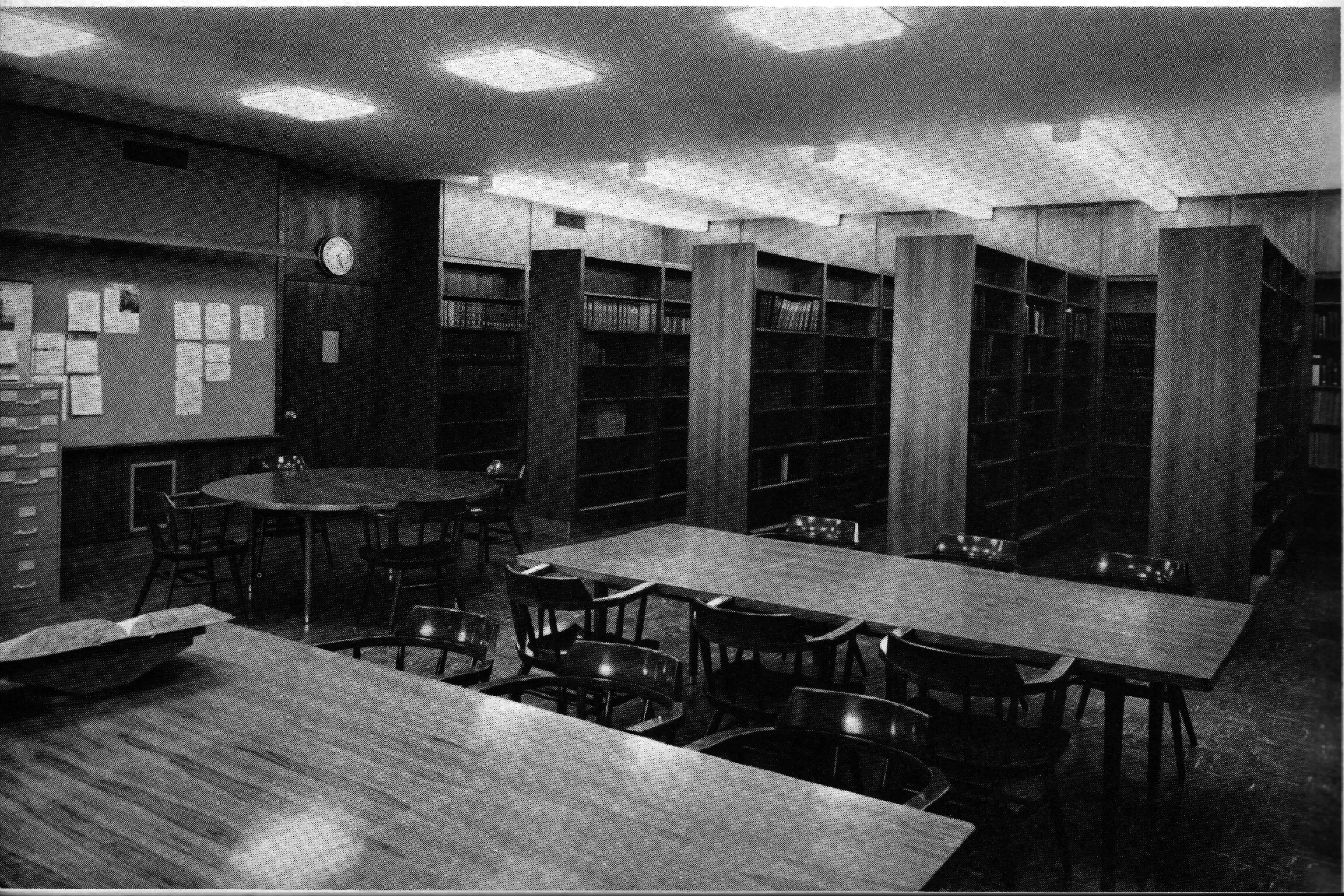
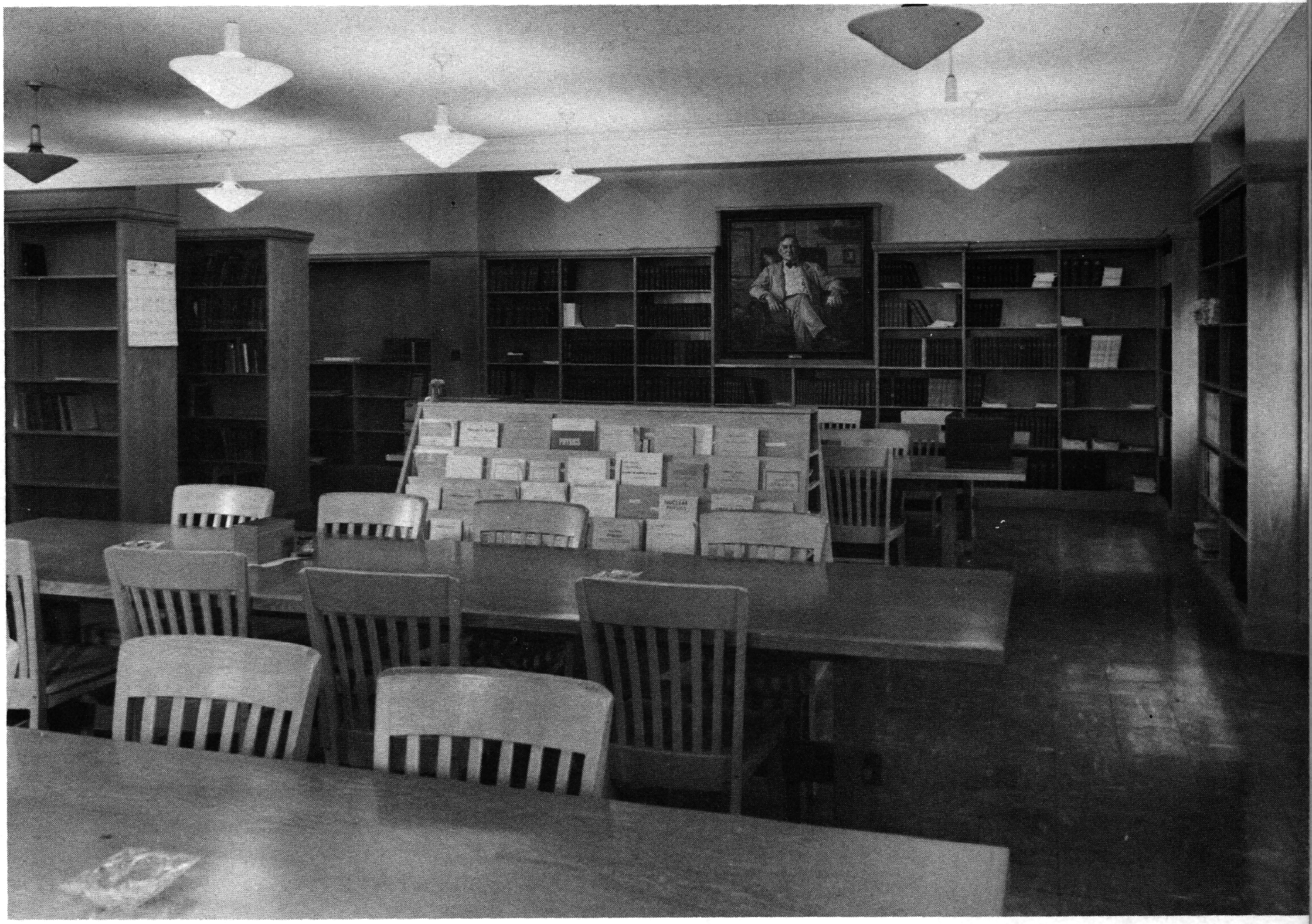
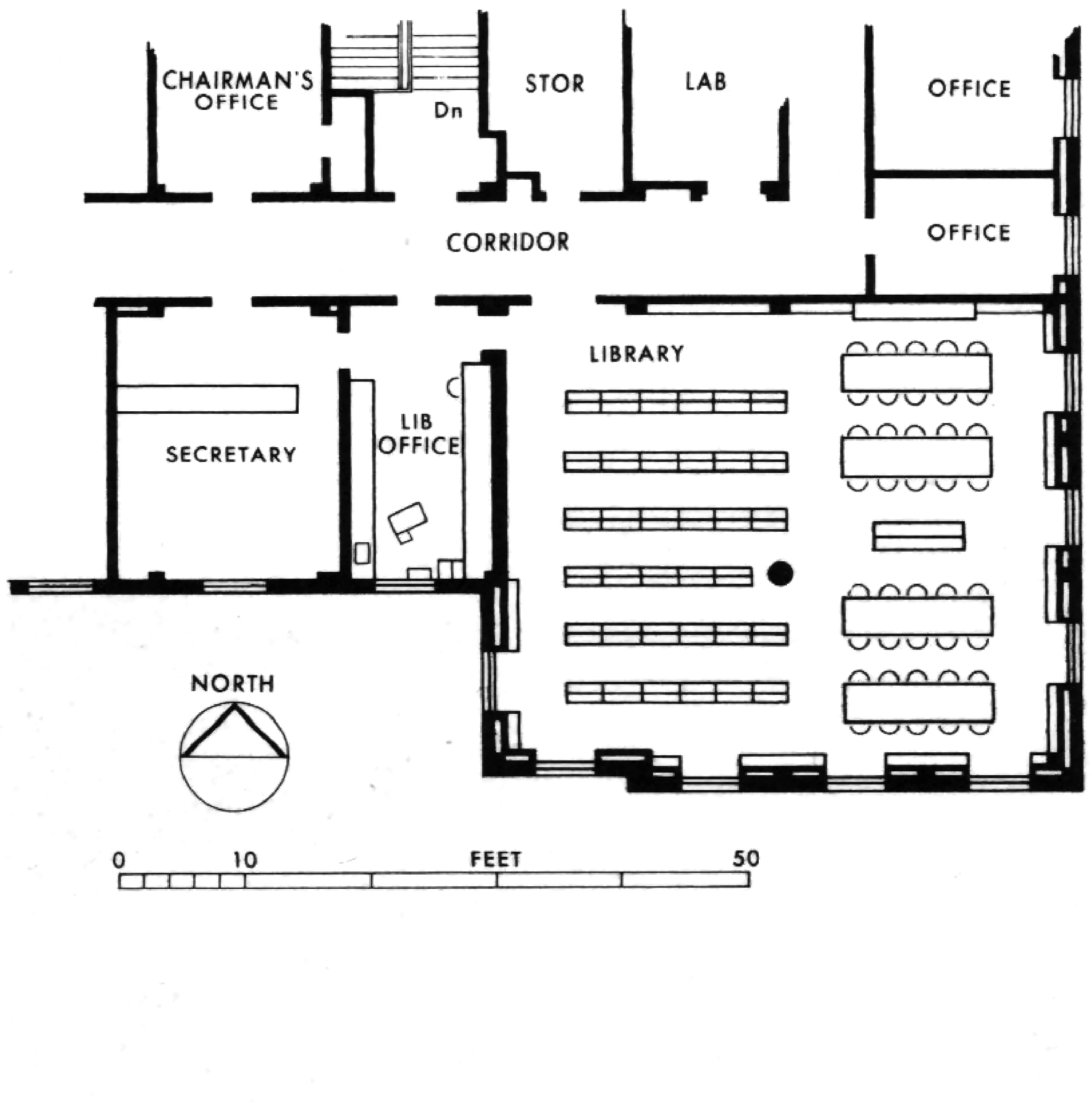


Figure 2. Physics library in the Olin Physics Building at Worcester Polytechnic Institute (Chapter 4, Figure 15).






CHAIRMAN'S OFFICE
Dn
STOR
LAB
OFFICE
CORRIDOR
OFFICE
LIBRARY
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LIB OFFICE
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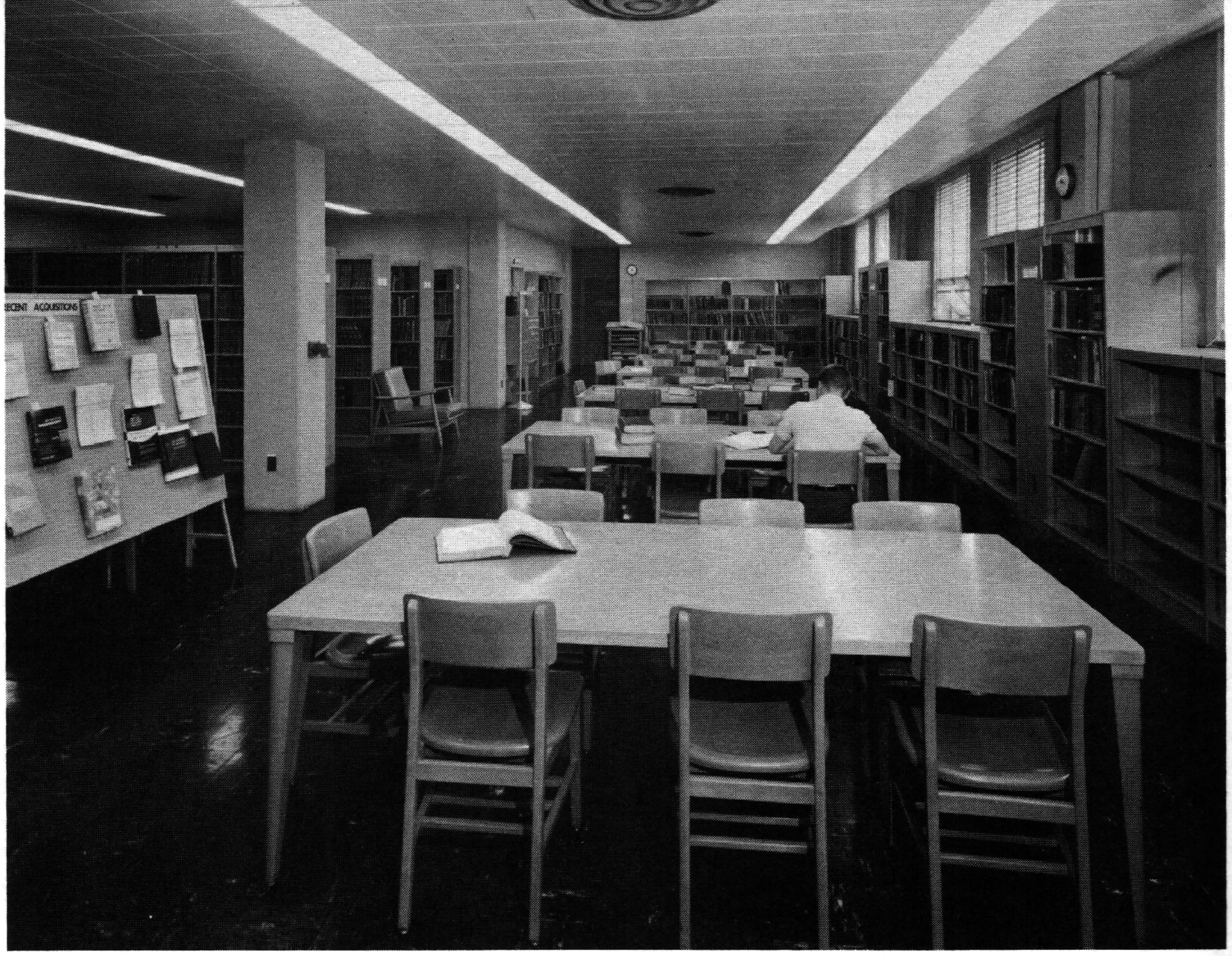
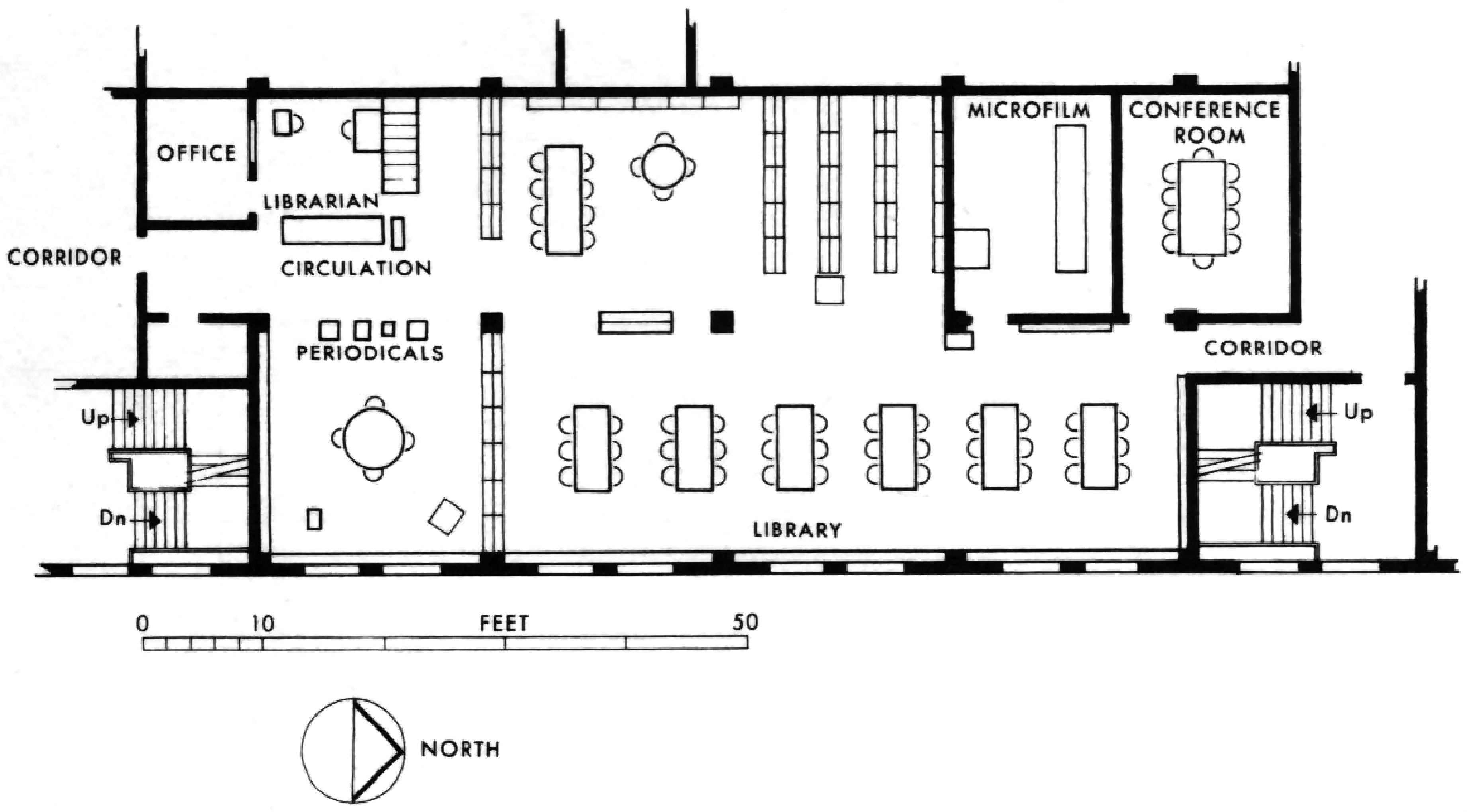
50

Figure 3. Physics library in the new physics building at the University of Virginia (Chapter 4, Figure 13).


RECENT ACQUISITIONS


OFFICE
LIBRARIAN
CIRCULATION
CORRIDOR
PERIODICALS
MICROFILM
CONFERENCE ROOM
CORRIDOR
Up
Dn
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LIBRARY
0
10
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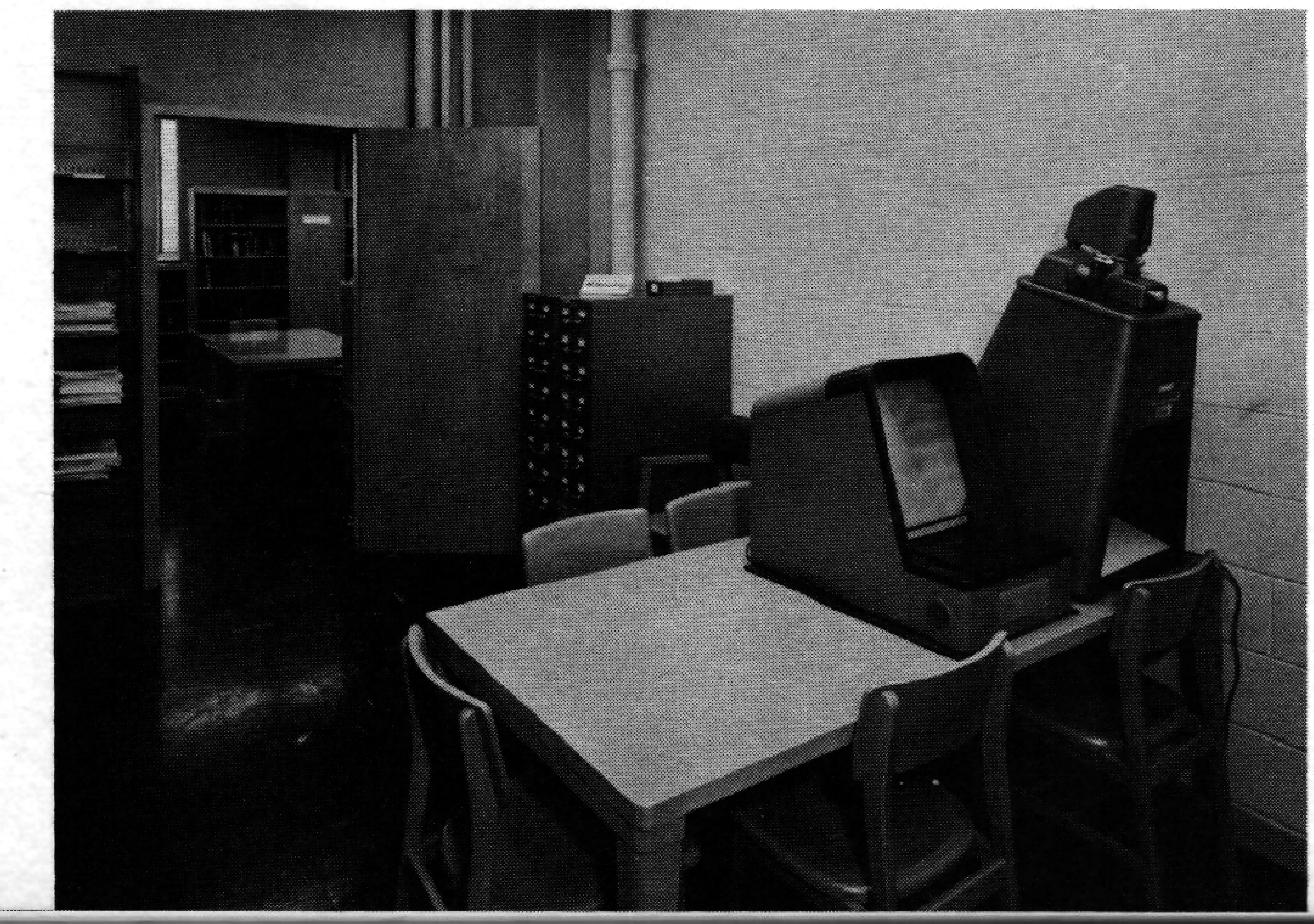
50
NORTH

Figure 4. Physics library in the new physics building at the University of Illinois (Chapter 4, Figure 6). Side room (below left) houses special reports and microfilm and microcard storage and reading facilities. AEC reprints are on microcard in the file near the door. Conference room is shown below right.



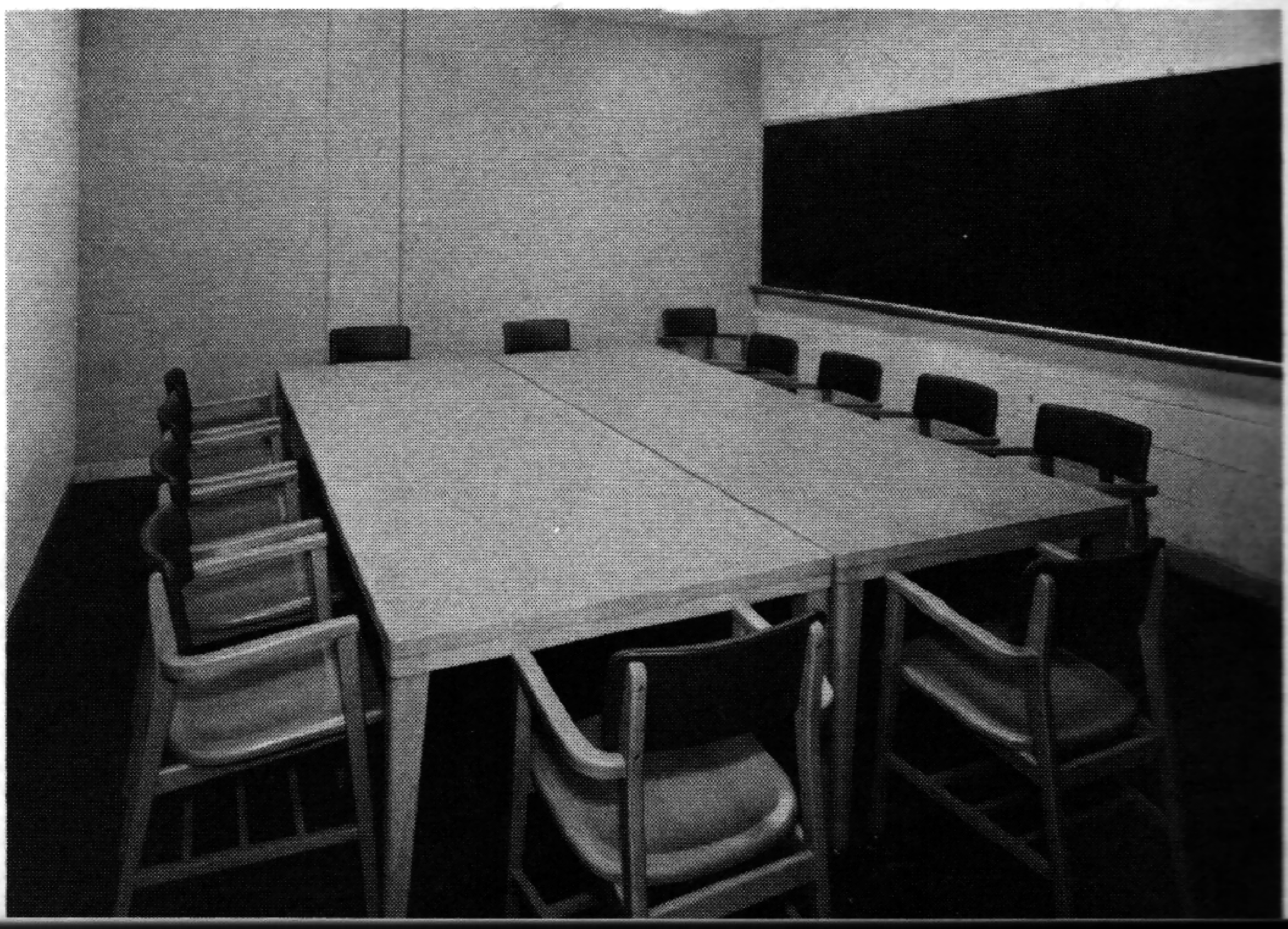


Table I. Physics Library Facilities at Three Selected Institutions

Institution	Total Area (Square Feet)	No. of Books	No. of Volumes of Bound Journals	No. of physics journals currently being bound	No. of seats in library	Professional Library staff
Worcester Polytechnic	1100	1500	1000	22	24	0
Univ. of Virginia	2000	3500	2500	76	40	⅓
Univ. of Illinois	3600	5000	5000	210	72	3

Table I gives certain data for the libraries at these three institutions—floor area, number of books and bound journals, number of journals currently being bound, seating capacity of the library and the number of professional librarians on the staff. Table II gives some idea of the relative numbers of persons served by the three libraries. Each department also provides service courses for other departments, including engineering, but most of these have little call upon the library.

Table II. Number of Academic Physicists on the Staff and Degrees granted at Three Selected Institutions

Institution	No. of Academic Physicists*	Degrees Granted**					
		1958–1959			1960–61 (estimated)		
		BS	MS	PhD	BS	MS	PhD
Worcester Polytechnic Institute	13	10	1	0	14	3	0
Univ. of Virginia	12	3	8	7	12	24	15
Univ. of Illinois	65	34	46	16	55	50	20

* Data from *Directory of Academic Physicists* prepared by the American Association of Physics Teachers and the American Institute of Physics.

** Data from *1959–60 Survey of Enrollments and Degrees Granted to Physics Majors* prepared by the American Institute of Physics.

Each library has approximately half its area devoted to stacks. Open stacks are accepted practices in these libraries as in most physics and divisional libraries. As expressed by Cowgill and Pettingill, "To make the use of books inviting, most university libraries now have open stacks . . . Like supermarkets, libraries accept unavoidable losses in order to promote access to goods."[1] Current journals are displayed in special racks, several types of which can be seen in the accompanying photographs.

The physics library at Worcester Polytechnic Institute is essentially a self-service library, and the library at the University of Virginia has the services of a librarian only part time. Special library services, such as microfilm and inter-library loan, are therefore provided at these institutions through the main library. On the other hand, the much larger physics library at the University of Illinois has a professional staff of three persons with an office and workroom for them in the library area. Additional facilities are provided in two 15-by-20-foot side rooms at Illinois. One houses special reports; such as, AEC Reprints, and microfilm and microcard reading and storage facilities (Figure 4c); the other is furnished with a table and chairs and a chalkboard, and serves as a conference room where discussions can be held and smoking is allowed (Figure 4d).

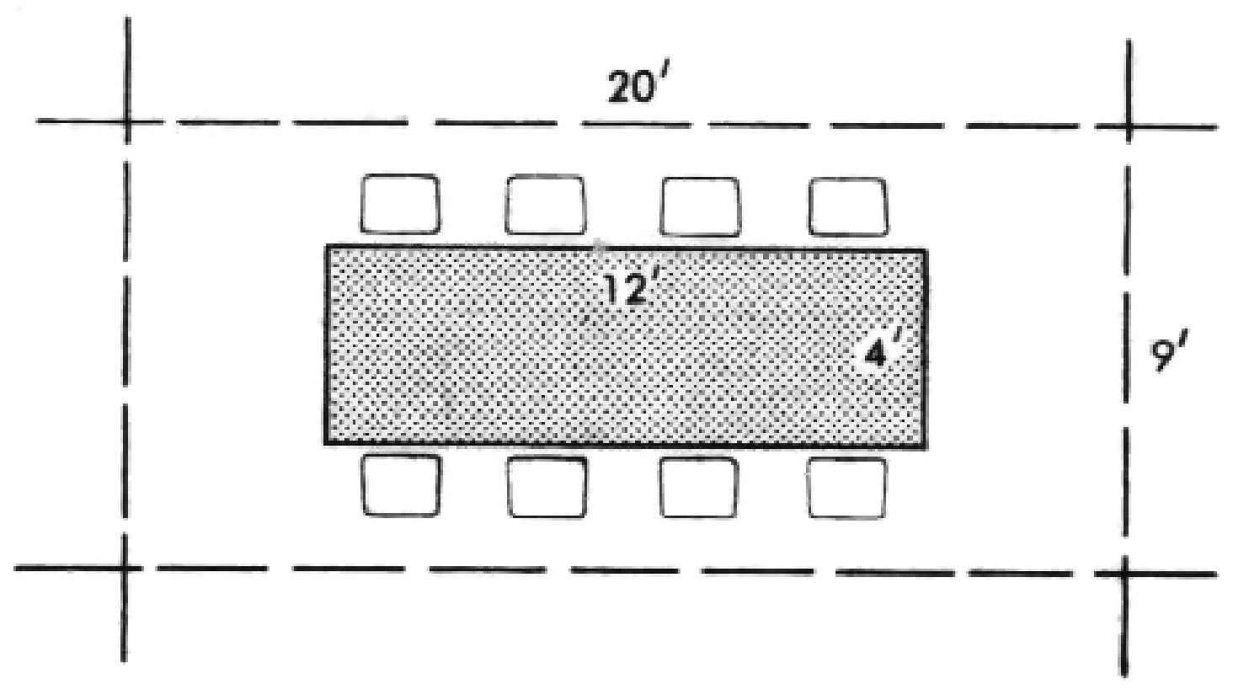


Figure 5. Layout of section of reading room to accommodate a 4-by-12-foot table seating 8 persons; about 22.5 square feet per seat.

Figure 5 suggests how one can arrive at the approximate space required for tables and chairs in a reading room. By seating 8 persons at 3-foot intervals at an array of tables each 4 by 12 feet, one must allow at least 22.5 square feet per person. Chairs at tables in the reading area should be comfortable, for they are frequently used for prolonged periods of study. They should be roomy and, preferably, have arms. The framework of the table should be recessed or otherwise constructed so that chairs with arms can be shoved part way under the table when not in use. This not only gets the chairs out of the way, but also yields psychological benefits by giving the room a more orderly appearance.

An area is frequently set aside in a library for more informal seating and is equipped with upholstered chairs. This area is usually in the vicinity of the racks which display current journals.

Carrels for individual study are also frequently provided in libraries. These may be located among the stacks or in an area especially set aside for them. They usually consist of open-ended cubicles to provide a degree of privacy. On the other hand, individual tables without partitions between them are satisfactory in a small library, as at Worcester (Figure 2).

Some institutions with large physics enrollments have found it desirable to have two physics libraries—one for the use of undergraduates and the other for research. Views of the two libraries provided at Harvard are shown in Figure 6.

Institutions which have extensive research programs accumulate research records in great numbers, and these must be preserved—especially privately circulated reports of work done under government contracts. Figure 7 shows the special Documents Room set aside for this purpose in the Compton Laboratory at Massachusetts Institute of Technology.

Lighting

The illumination in a library must be adequate for the work to be done. The recommendations below are given by Logan and are based on the work of Dr. Blackwell and his associates at the University of Michigan

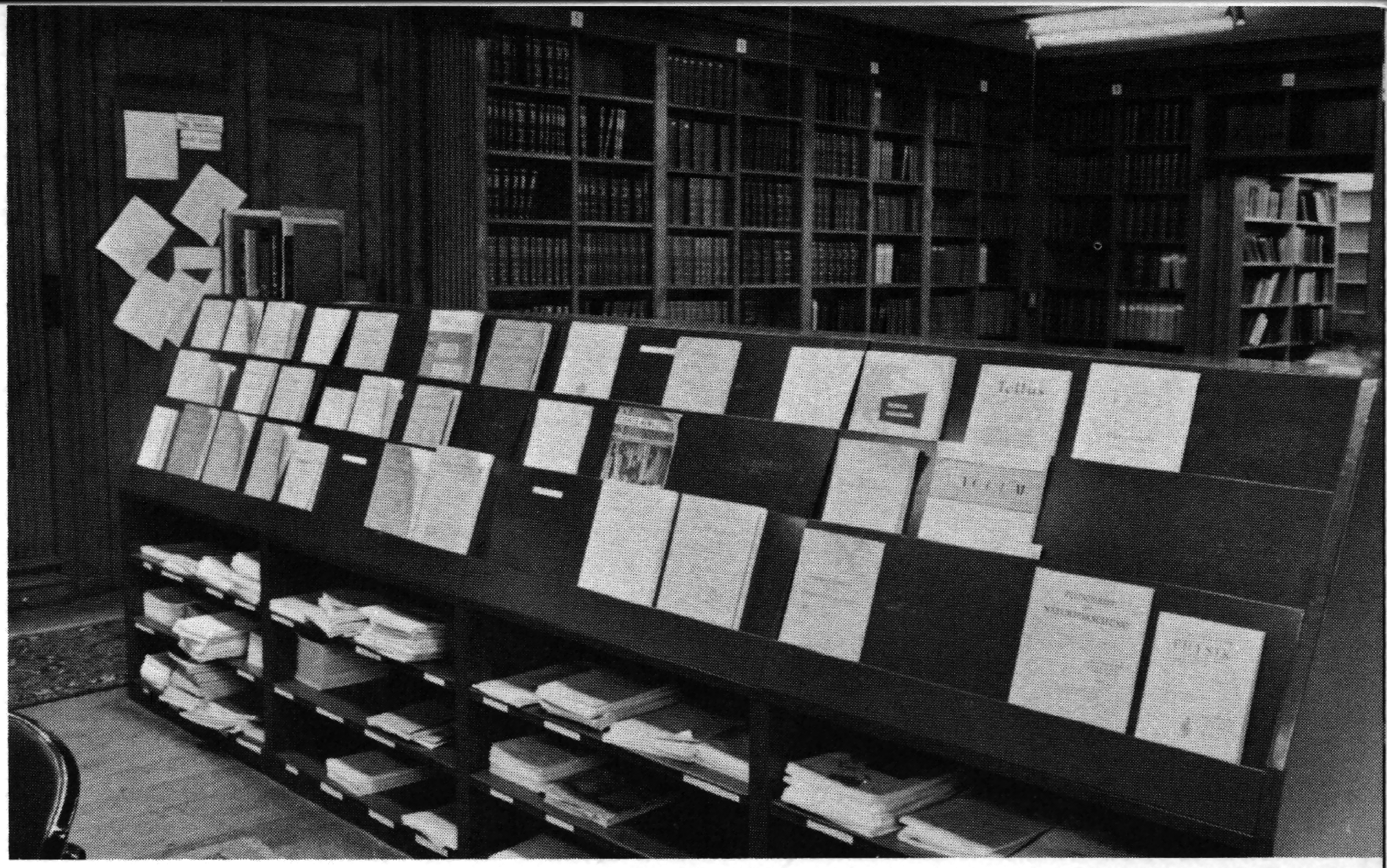
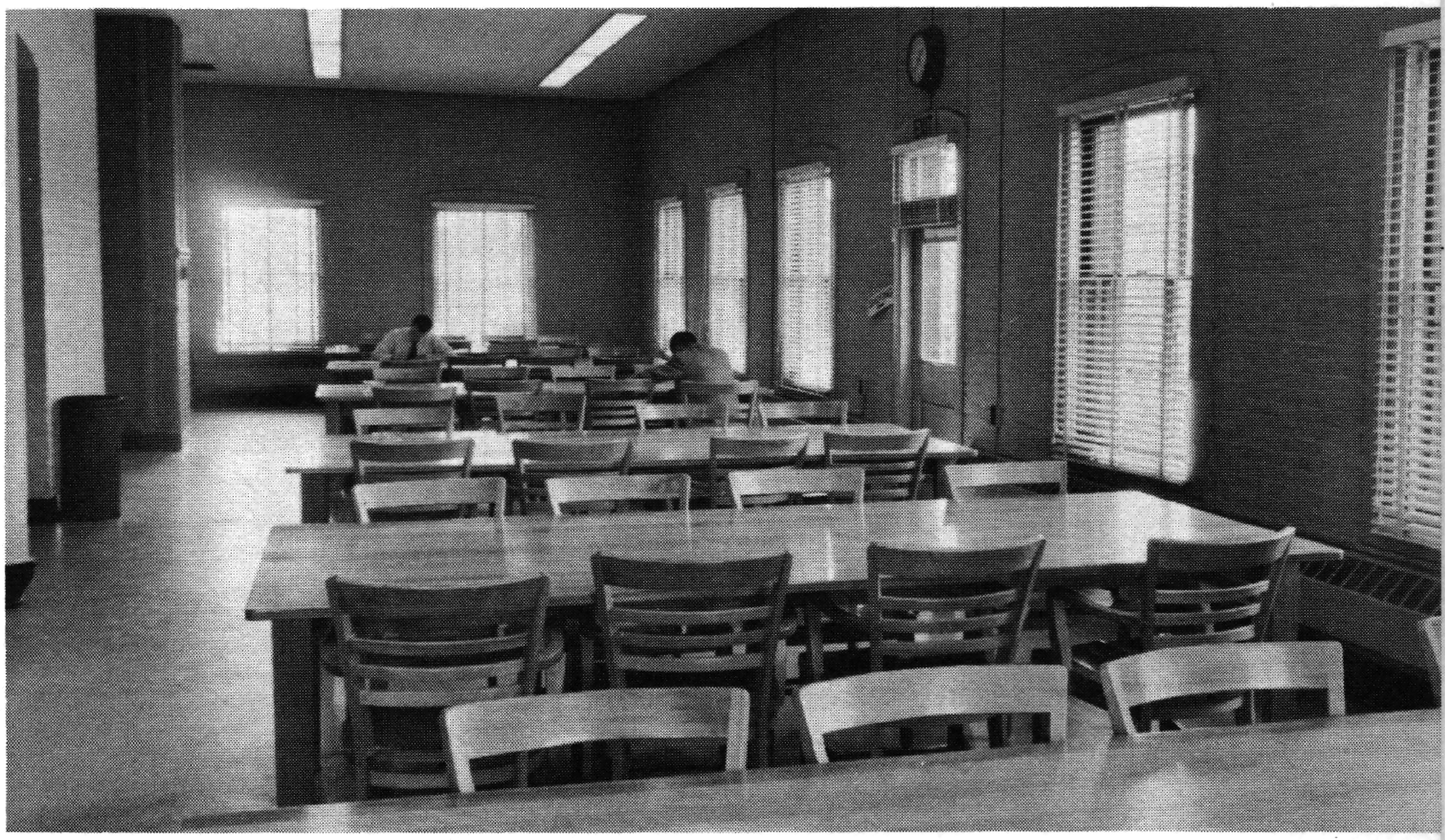


Figure 6. Reference room in the graduate research library in the physics department at Harvard University. Reading area in the physics undergraduate library is shown below.



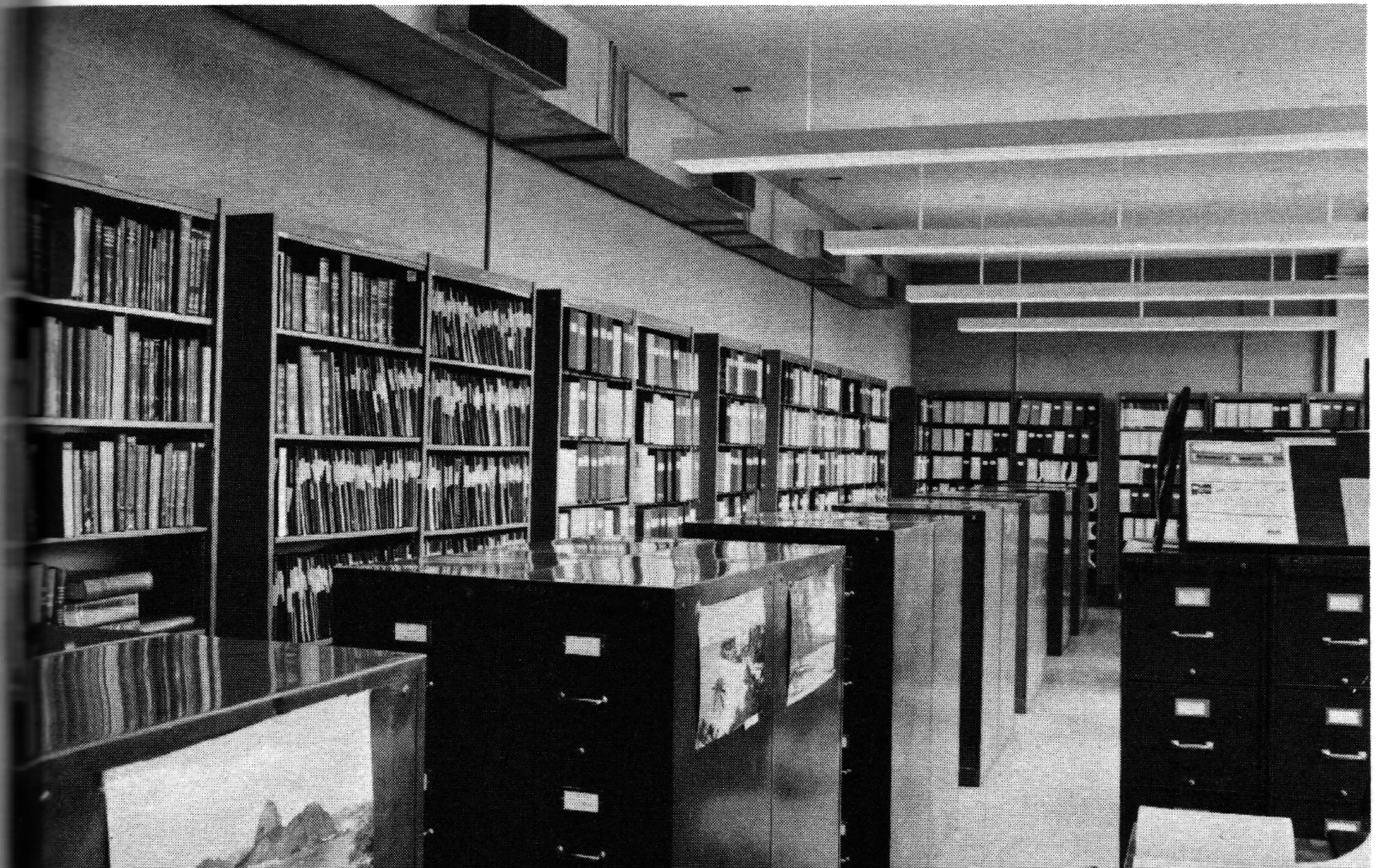


Figure 7. Documents room in the Karl Taylor Compton Laboratory at Massachusetts Institute of Technology.

in which "the relationships between the size of detail to be seen, its contrast with the background and the level of light required to see at a given rate in assimilations per sec" have been worked out.[2]

AREA	ILLUMINATION (Foot Candles)
browsing area	50
catalog department	70
carrels	70
conference room	30
documents	70
foyer and lobby	20
offices	70
reading area	70
reference room	70
storage space	20
work rooms	70

Ventilation and Air Conditioning

A library should be properly ventilated and air-conditioned. Both are necessary if it is to be used efficiently throughout the year. Well planned artificial ventilation is, of course, required. Windows provide only ill-directed and intermittent circulation of air at best. Furthermore high temperatures during the summer militate against efficiency as do low temperatures during the winter. Just as heating is required in the winter, air conditioning is required in the summer. Moreover, where the humidity is high, air conditioning is needed to preserve books. When one is seated at his desk, in his office or in the library, studying or trying to write, high humidity seems particularly oppressive and actually decreases one's efficiency. A good circulation of air is helpful, but it is still better if the air is properly conditioned for human comfort.

Keys to the Library

Both faculty and students are customarily given keys to a departmental library. When physics books are absorbed in an all-university library, they become less accessible not only because of distance but also because keys to the library are normally restricted to the professional library staff and physicists frequently desire to use the library when it is closed. Keys to departmental libraries, on the other hand, are usually distributed quite generously to "those who can show a need for one." Between these extremes lie the policies of the divisional and interdepartmental libraries where the policy on keys is variously handled depending in part on the size of the library but also on its past experience. Where keys are not distributed, more books are checked out and retained for longer periods, and thereby become less accessible to others. However, at most universities that have interdepartmental libraries, keys are available to senior faculty members in the departments concerned and frequently keys are more widely distributed. At one institution where keys to the Physics-Mathematics Library are given to "all faculty, research associates and graduate students," the policy was established because "keeping the library constantly available to all qualified people is considered worth the ever-present problem of missing books, most of which eventually return."

Space Saving Devices

A number of steps to save space can be taken by a library that is becoming over crowded. In the first place, the stacks should be frequently combed for unused material. Old editions of standard textbooks and reference books can be destroyed or sold. Other books and bound journals which are rarely used should be placed in storage in less valuable space, perhaps in extra tall cases in narrow aisles.

Considerable space can be saved by more extensive use of microfilm and microcards. About 2400 ordinary book pages can be stored on 100 feet of 35 mm film; 1600 pages, on 16 mm film. Each side of a 3-by-5-inch microcard will accommodate up to 60 pages. The current rapid growth of libraries of all types will require that increased advantage be taken of such space saving methods.

Five-drawer file cabinets can be used for reports, pamphlets and bulletins instead of the more conventional four-drawer units. Stack shelves can be extended to the ceiling, provided floor loading is sufficient to permit the added weight. Ladders must, of course, be provided for reaching upper shelves. Compact shelving that is deep will allow more books to be stored in a given stack area. In one type, books are stored in deep shelves that pull out like drawers in a filing cabinet. The library in the science building at Grinnell College makes use of such shelving (Figure 8). Since such compact storage is not conducive to browsing, it is most suitable for bound journals and books which are most likely to be located by card index.[3]

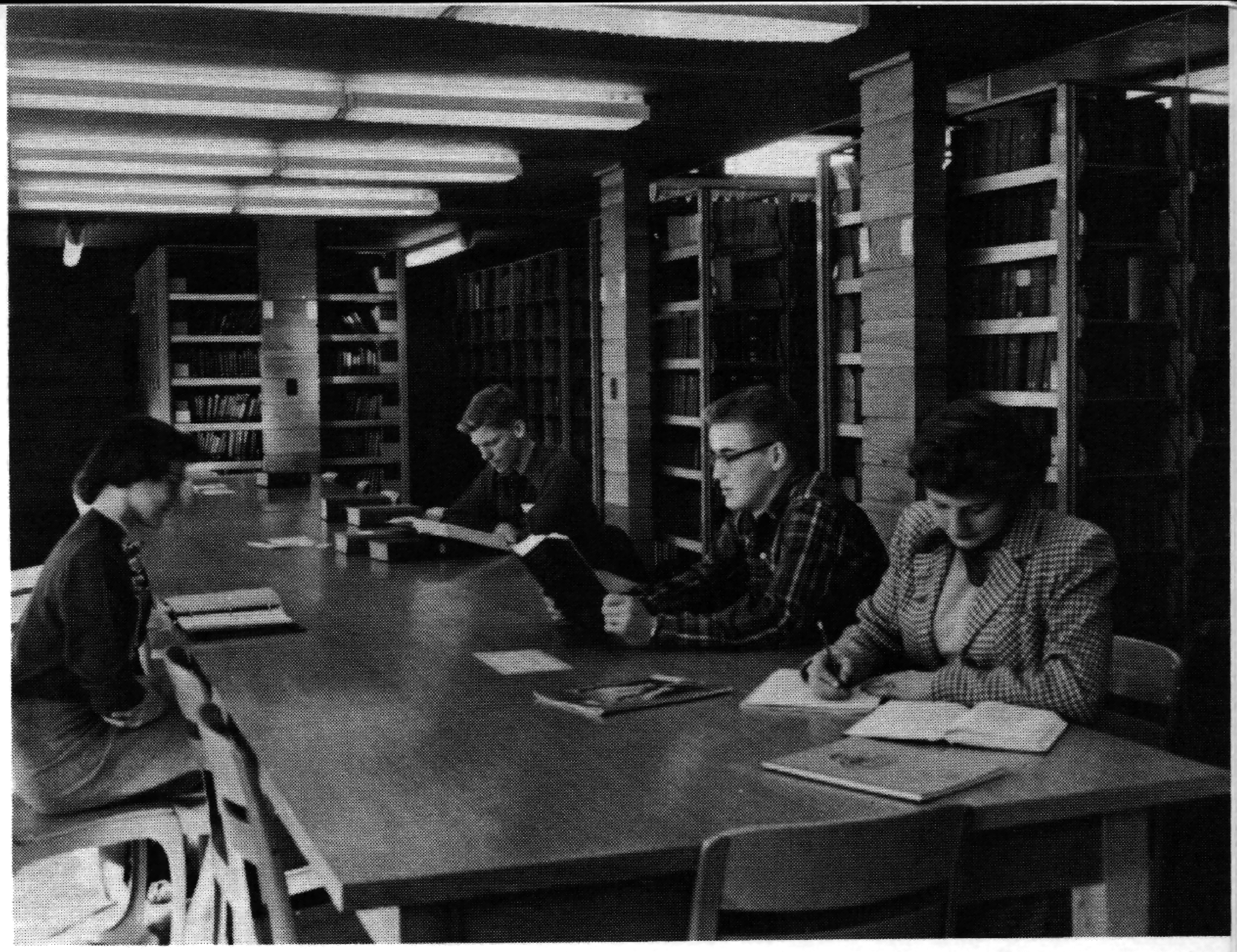


Figure 8. Science library in the Science Building at Grinnell College. Note the use of drawer shelves for compact book storage.

CHECK LIST—LIBRARIES

The following check list has been adapted in large measure from a check list prepared by G. E. Runge and H. M. Pyle in the Special Libraries Association Monograph No. 1, entitled *Libraries for Research and Industry.* This monograph is out of print, but a new publication, *A Check List for the Organization of a Company Library,* is being published in 1960.[4]

I. Location

- A. Accessibility to all clientele
- B. Freedom from noise of machines, vibrations of machinery, and fumes of laboratories
- C. Protection against flooding (not under a laboratory)
- D. Future expansion for functional areas without complete relocation as more space is required. (Use movable partitions, for flexibility of space and layout.)

II. Structure

- A. Walls between library and adjoining areas
    1. Movable partitions
    2. Structural walls

- B. Doors
  - 1. Location; number; size
  - 2. Locks—one lock number and one key for all doors
- C. Windows
  - 1. Exposure
  - 2. Location and Size
  - 3. Provision for opening if building is air-conditioned
- D. Heating and air conditioning
  - 1. Location of units and outlets with respect to partitions and furniture arrangement
  - 2. Temperature and humidity
- E. Floor
  - 1. Floor load—30 pounds per cubic foot of stack range for books, shelves, and supports
  - 2. Sub-flooring—materials and structure
  - 3. Covering qualities—durability, maintenance, comfort, noiselessness, appearance, cost
- F. Outlets
  - 1. Electric—for microfilm and micocard readers, typewriters, dictating machines, marking stylus, clocks, duplicating machines, photographic equipment
  - 2. Control panels and/or light switches
  - 3. Telephones
- G. Lighting
  - 1. Incandescent or fluorescent
  - 2. Recommended illumination levels
- H. Ceiling
  - 1. Material
  - 2. Color and light reflection
- I. Fire Protection
- J. Vault—for lab notebooks, classified materials, etc.
- K. Book lift and elevator for storage area on another floor
- L. Separate building facilities—loading dock; freight elevator; service work

III. Furniture and equipment layout

- A. Reading and study area—55 to 60% of total floor area
  - 1. General Recommendations
    - *a.* Rounded corners on furniture
    - *b.* No unnecessary dust-catching grooves or projections
    - *c.* Sheet asbestos covering on backs, ends and under sides of all cases, seats, tables and other fixtures exposed to radiators or heat pipes
    - *d.* Glass or metal glides on all movable pieces; thick waxed linoleum bradded to base of heavier pieces; brass shoes on desk and table legs
    - *e.* Samples of materials including wood and hardware (showing finish) submitted by contractor for approval
    - *f.* Classification of furniture in groups and let under more than one contract
  - 2. Tables—29 inches high
    - *a.* Rectangular top
      - (1) 36 by 60 inches for 4 readers
      - (2) 36 by 78 inches for 6 readers
    - *b.* Circular top
      - (1) 42-inch diameter for 4 readers
      - (2) 48-inch diameter for 6 readers
    - *c.* Carrel tables—for individual work areas
  - 3. Chairs—18-inch standard height for adults
  - 4. Aisles
    - *a.* 3½ to 4 feet between ends of tables
    - *b.* 5 feet between tables and between tables and walls
  - 5. Reading machines and storage—microfilm and microcard
  - 6. Cubicles or study rooms

7. Shelves and reading space
    - *a.* abstract journals
    - *b.* indexes

B. Service area for reference and circulation activities located near library entrance and reading area
1. Circulation desk—6-foot minimum space in front
2. Card catalogs—5 foot aisle in front
3. Basic reference collection near circulation desk and reference desk
4. Telephone with muted bell

C. Storage area
1. Book stacks (the most nearly permanent installation in the library)
    - *a.* accessibility to reading area and staff
    - *b.* expansion and rearrangement within the library
    - *c.* future expansion as building is enlarged and library requires more space
    - *d.* use as partitions wherever possible
    - *e.* space estimates (plan for 10 years growth)
        - (1) 7 ordinary technical books per running foot of shelf
        - (2) 5 bound periodical volumes per running foot of shelf
    - *f.* Aisles—30-inch minimum, 36-inch preferred
2. Special shelves for new books and periodicals display
3. Files
    - *a.* Arrangement
    - *b.* Size, type and locks
        - (1) legal and letter
        - (2) special (slides, catalogs, patents, microfilm, records, etc.)
4. Inactive Storage—location; need for book lift, elevator, carts

D. Work Area
1. Librarian's office—accessibility to staff work area and reading room
    - *a.* Partitions
        - (1) glass, head height
        - (2) glass and steel
        - (3) solid partition
        - (4) with window
    - *b.* Equipment: desk and chair; visitor's chair; book shelves or book case; telephone; table; file and typewriter
2. Library office equipment—desk; chair; wastebasket for each person; shelving for staff's reference books; card catalog for working indexes; files for library records and correspondence; telephone; buzzers; typewriters; clock
3. Work room
    - *a.* Location: adjoining library office and corridor with connecting door for deliveries.
    - *b.* Equipment: work table and chairs or stools; running water; shelving for work in progress; electric outlets

E. Expansion of internal areas
1. Equipment and furniture for partitions wherever possible
2. Standard-size equipment for interchangeability
3. Space for expansion (Leave free area the size of standard equipment.)

F. Special Features
1. Exhibit areas
2. Decorations—murals and other wall decorations; draperies

G. Color
1. Light reflection (A light-colored wall opposite the windows diffuses the light and decidedly increases it where most needed.)
2. Psychological effects

12. Laboratories and Classrooms for High School Physics

INTRODUCTION

This chapter contains suggestions for planners of facilities for physics in secondary schools. Although it comes at the end of the book, the discussion of high school physics is not an afterthought. From the beginning of the physics buildings project, we have been interested in new designs for school laboratories and in ways of providing school planners with as much helpful information as possible.

The Role of High School Physics

High school physics has strong claims for consideration in a book on physics facilities. The first systematic treatment of physics for many students occurs in the eleventh or twelfth grade. A successful experience with a good high school physics course carries the student of science and engineering into his higher education with an interest in the exact sciences and a readiness to engage in precise, quantitative, sequential reasoning about the physical world. For the student preparing for a career in other fields, a good physics course provides an insight into the scientific enterprise and a basis for judgment on numerous public problems in a technological age. In 1960, approximately one quarter of high school graduates had taken a one-year course in physics. The number of physics students and the percentage of students studying physics are both on the rise, and it seems evident that physics teaching and learning will be increasingly important activities in schools.

Because the nation needs well-informed citizens and well-qualified scientists and engineers in ever increasing numbers, facilities for teaching physics effectively in high schools are an appropriate concern not only of school planners, but of all who want to see the quality of American education raised. Provision for higher-quality instruction in physics and for greater numbers of physics students in the future cannot be overlooked in designing new schools.

School laboratories and classrooms are interesting for another reason, however. Many innovations have been made in high school physics facilities, perhaps more than in classrooms for colleges and universities. Combination classroom-laboratories and project rooms, for example, have developed rapidly in schools. College building planners will find in the plans of some schools valuable suggestions for the design of introductory college physics laboratories.

Changes in Educational Programs

Educational programs are undergoing a steady evolution these days under the triple pressures of growing enrollments, technological change in educational tools, and expanding knowledge in all fields of study. Ample documentation of the growing problems of the schools in providing educational opportunities is available.[1, 2] Here we will describe a few of the proposed solutions that will eventually affect the teaching of many subjects, including physics, and that will be reflected in building design. *Team teaching* is being successfully used in some schools to meet the shortage of expert teachers by more efficient use of the teacher's time. As developed at Wayland (Massachusetts) Senior High School, for example, a teaching team for a subject includes the subject's leading teacher, a person of considerable experience and depth of preparation who acts as team leader; several other teachers; several interns or student teachers; and several clerks.[3] Interns engaged in apprentice teaching are supervised by the teachers. Clerks and other assistants relieve the teachers of many of the routine clerical and supervisory duties that nibble away at the teacher's time. *Classes of varying sizes* permit a more flexible educational program at Wayland and other schools following this plan. Lecture groups, taught by the team leader, are several times as large as the ordinary high-school class and are brought together for the initial presentation of subject matter or for demonstrations that can be effectively given to large groups.[1, 3] Recitation classes and seminars are medium-sized groups.

Educational television is being tested in a variety of school situations ranging from complete instruction in several subjects to occasional programs that supplement instruction by the classroom teacher.[1, 4] Although the extent to which television teaching will be depended upon for basic instruction has not been established, it seems clear that both broadcast and closed-circuit television will be a valuable adjunct to classroom teaching in the future by permitting the teacher to introduce to his class persons, events, and phenomena that would otherwise be inaccessible to them. Special building facilities can be installed to permit television to be used efficiently and flexibly as a classroom tool.[4]

Teaching machines are under study in schools as a means of furthering learning, of developing better teaching methods, and of freeing teachers from the supervision of rote learning.[1] Some of these machines provide drill exercises for the student and enable him to test himself on his grasp of rote elements of his studies; others provide playback exercises in pronunciation as aids in learning modern foreign languages.

Changes in Physics Teaching

Physics teaching, too, is changing. Foremost is a renewed insistence on *laboratory experiments by students.* Laboratory work is of prime importance in teaching introductory physics. Many schools are emerging from a period in which the student laboratory had fallen into disuse into one in which laboratory teaching is given equal billing with teacher demonstrations and classroom discussion. Adequate time, space, and equipment are needed for student experiments. *Television teaching of physics* is being tested; the Harvey White film-television course in high-school physics, and the Continental Classroom refresher course in physics for high-school teachers have been developed to provide physics courses in schools where a qualified physics teacher is not available and to assist physics teachers in service to keep up to date in their preparation in physics. *New physics courses* are evolving. The Physical Science Study Committee is developing a modern course in physics for high schools and is preparing materials for such a course. Space is not available here for a review of the content and the objectives of high school physics courses or of new physics programs. See *Physics in Your High School,* prepared by the American Institute of Physics, for a discussion of these topics and for comprehensive recommendations for the improvement of physics teaching.[5]

Changes in School Buildings

Although this chapter will concentrate on the problems of planning physics facilities in schools, it should be noted that the school buildings being constructed these days house a variety of activities and do this with increasing effectiveness. Physics instruction shares in the total resources—including building space and facilities—of the entire school. Just as physics contributes greatly toward the objectives of a sound educational program, it needs the support of the other subject and service fields—the other natural sciences, English, mathematics, and counseling, to name a few. Exciting progress is being made these days in developing more suitable "packages" for all of these activities—school buildings that nurture educational activities without smothering them, that encourage learning, and that permit necessary change. The Hillsdale (California) High School, for example, employs the flexible subdivision of large open spaces in a so-called "loft plan" to permit the coalescing of space around work centers as the educational activities demand.[6] Newton (Massachusetts) South High School, when completed, will follow a "house" plan (Figure 1). Students at this school will be divided among three houses located in three separate buildings each with its own teaching staff.[7] A science building, gymnasium, auditorium, and library will complete the campus plan which promises to combine the superior facilities of a large school with the closer student-teacher contacts of the small one. Watch for the development of other solutions to the problem of finding a suitable building envelope for school activities. Gradually but to an increasing extent, the teaching of physics and the other high-school subjects will take place in a different setting from the familiar "foursquare" school building.

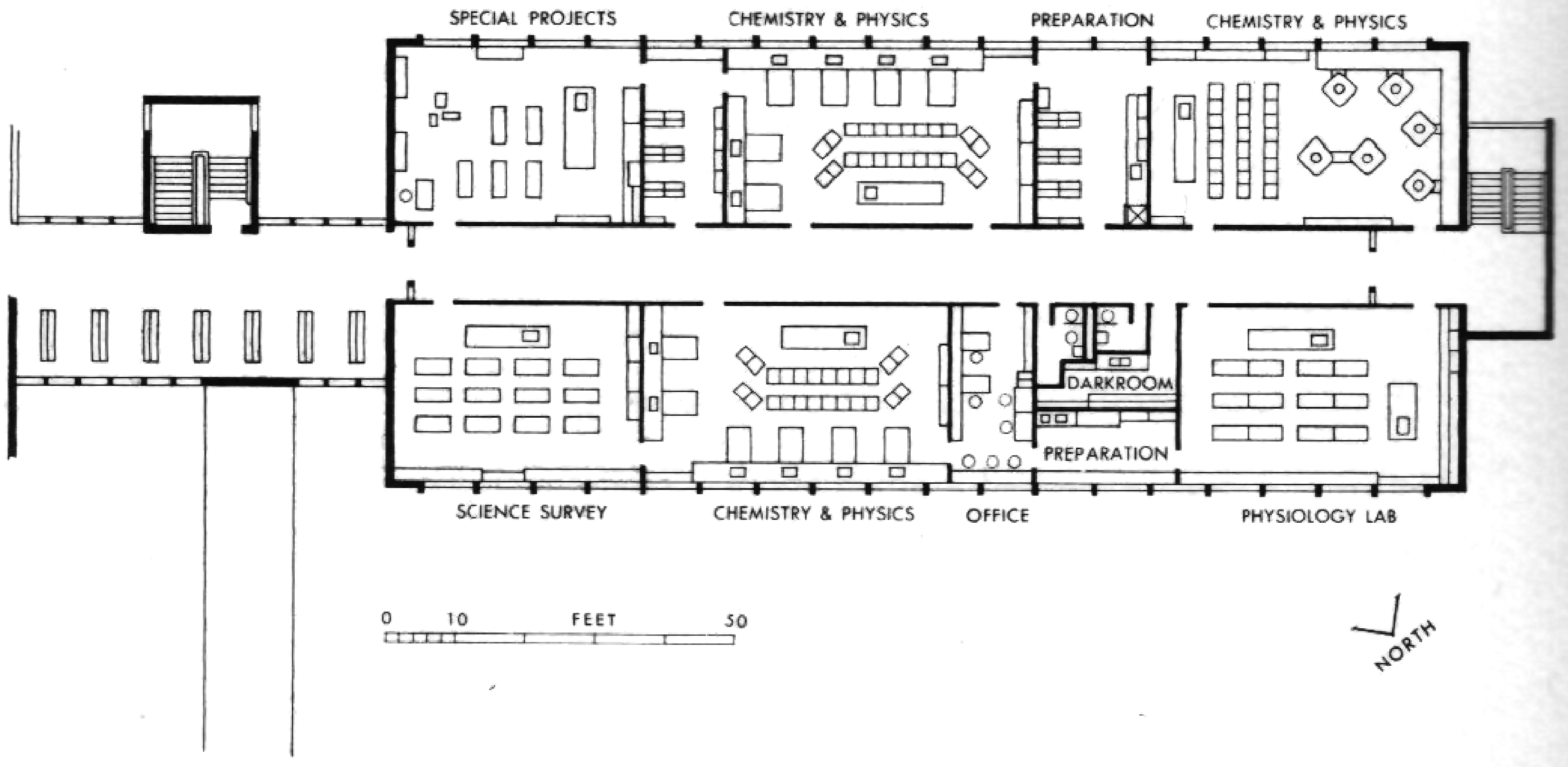
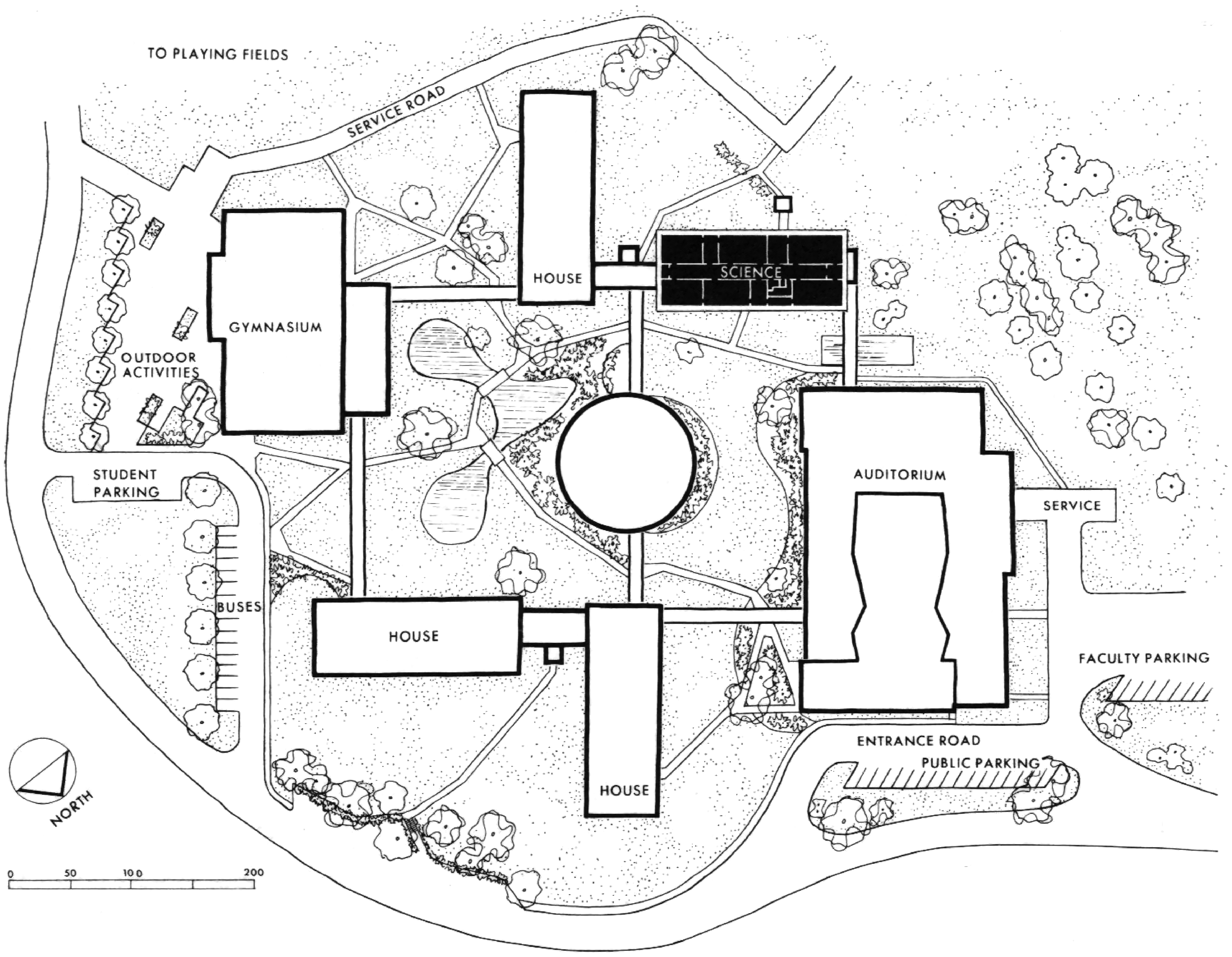

SPECIAL PROJECTS
CHEMISTRY & PHYSICS
PREPARATION
CHEMISTRY & PHYSICS
DARKROOM
PREPARATION
SCIENCE SURVEY
CHEMISTRY & PHYSICS
OFFICE
PHYSIOLOGY LAB
0
10
FEET
50
NORTH

Figure 1. "House" plan of Newton (Massachusetts) South High School. Second-floor plan, above right.


TO PLAYING FIELDS
SERVICE ROAD
HOUSE
SCIENCE
GYMNASIUM
OUTDOOR ACTIVITIES
AUDITORIUM
SERVICE
STUDENT PARKING
BUSES
HOUSE
HOUSE
FACULTY PARKING
ENTRANCE ROAD
PUBLIC PARKING
NORTH
0
50
100
200

ACTIVITIES IN HIGH SCHOOL PHYSICS

Before planning physics laboratories and classrooms, one should have a clear notion of what activities physics students and teachers will engage in. Naturally the physics course at one school will differ from that at another. Moreover, a school may offer more than one physics course or may offer additional courses in subjects related to physics, such as electronics and other vocational subjects. The activities—although not the subject matter and objectives—in all of these courses, however, are enough alike and their space requirements are similar enough that it makes sense to discuss here both the activities in a composite physics course and the building facilities that these activities require. We shall then offer some suggestions for planning physics facilities and some examples of how several schools of different sizes have designed rooms to house physics activities. At the end of this chapter we shall provide a check list of design requirements with references to helpful information to be found elsewhere in this book.

Experiments by students

In strong physics courses, the teachers place considerable *emphasis on student experiments.* Students work individually or in pairs, or—less desirably—in groups of more than two. They use physics apparatus, exploring the physical world in a variety of experiments in the sub-areas of physics such as mechanics, wave motion, sound, heat, electricity and magnetism, light, and atomic and nuclear physics. Students may investigate wave phenomena, measure the velocity of light, or count particles from a radioactive source. Direct contact with the apparatus and opportunities for the student to show initiative, ingenuity, and persistence in his experimental work are most important (Figure 2). The laboratory class—usually a group of about 24 students—ideally meets once or twice a week for a double period. Although single-period laboratory sessions are prevalent, many schools at present are attempting to replace them by double-period laboratory sessions. A 40- or 45-minute span of time is just not long enough for the class to set up its apparatus, carry on reasonably coherent experimental work, and put the laboratory in order for the next class. Laboratory classes with more than 24 students are feasible. To conduct them effectively, however, the physics teacher needs a qualified laboratory assistant, and the school must, of course, make a greater investment in laboratory equipment.

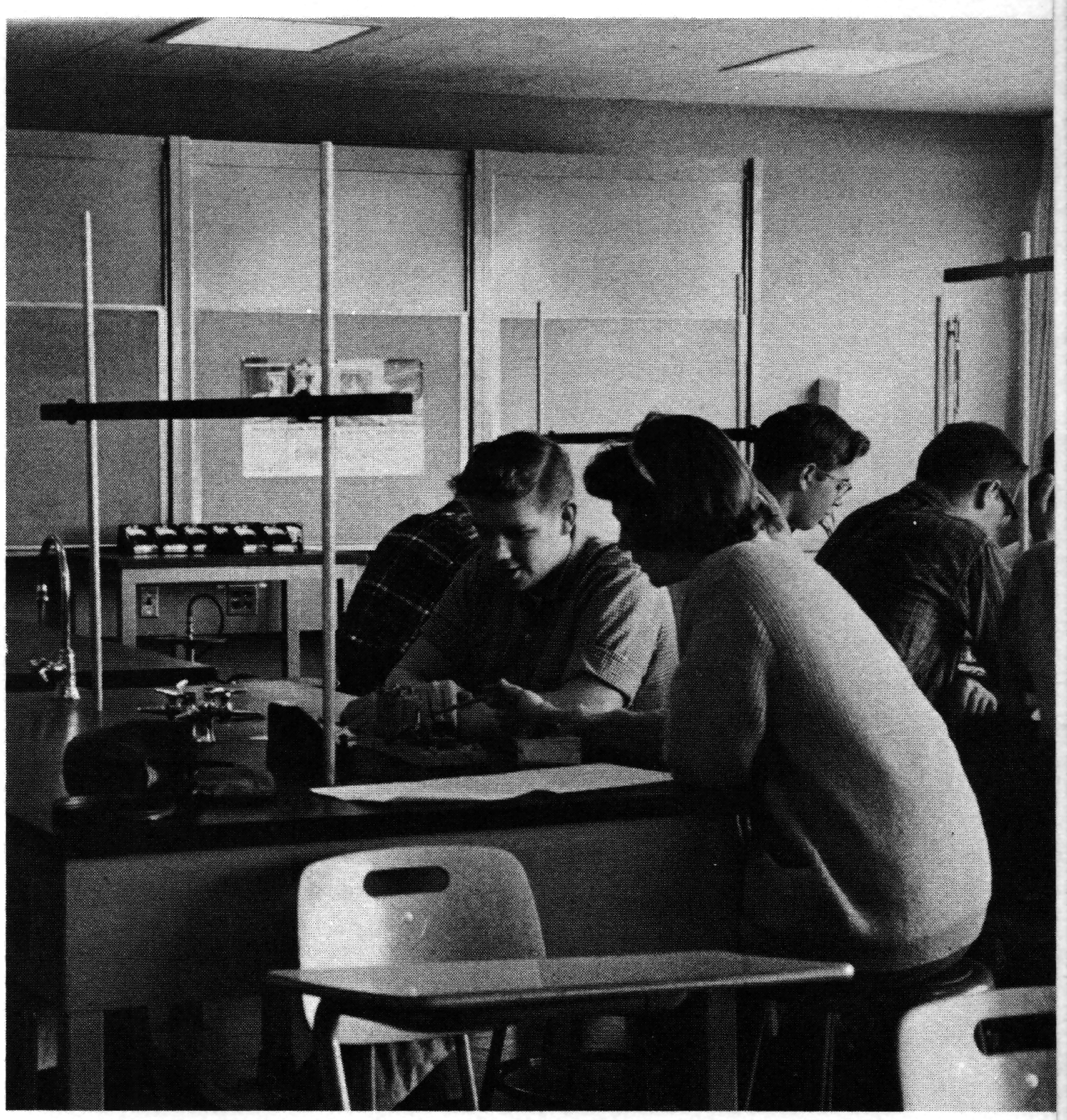


Figure 2. Students in the physics laboratory of Garden City (New York) High School. Note booths with vertically sliding doors for apparatus used in student projects (shown in background).

Experiments by the physics class are carried out on broad sturdy *laboratory tables,* or wall benches, provided with durable surfaces

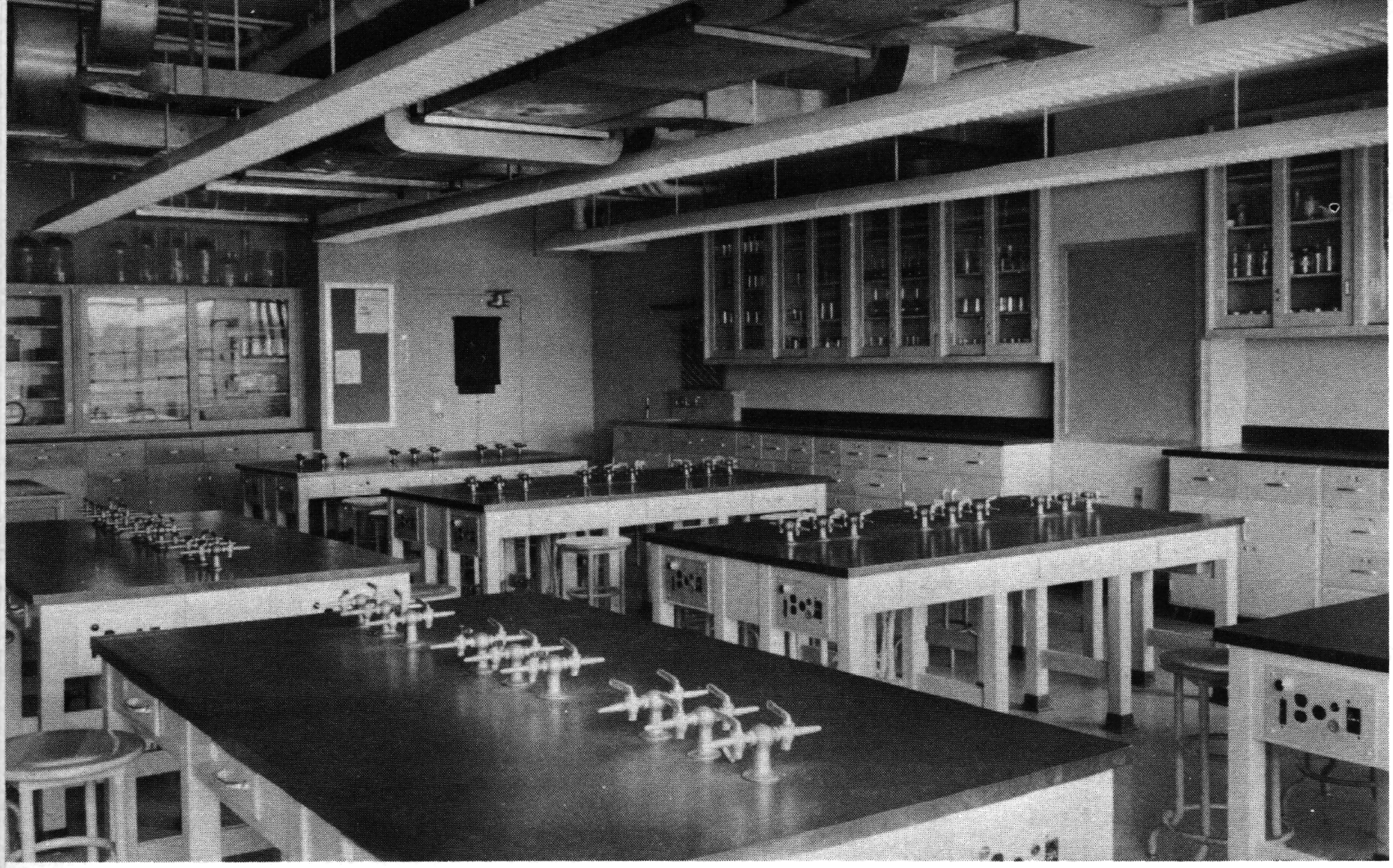


Figure 3. Laboratory tables for elementary physics at the Bronx High School of Science. Stopcocks on the table tops provide gas, compressed air, and rough vacuum. Electrical panels on the sides provide 120 volts ac, 0–120 volts ac, and 0–120 volts dc as well as switches and a pilot light.

and supplied with the necessary services (Figure 3). Some physics equipment is heavy, and much of it requires a stable support so that shaking or jarring the table will not disturb the adjustment of the apparatus. For both reasons, laboratory tables must be strongly built with adequate cross-bracing. Table drawers are usually not wanted since they are seldom used for apparatus storage and often become depositories for broken wires, waste paper, and dust. Physics students sometimes stand, sometimes sit, at their laboratory work depending upon the task of the moment. Hence a convenient table height—usually about 30 inches—is necessary for standing without excessive bending and for sitting on chairs with knees clearing the lower edge of the table.

Overhang of the table top of not less than 2½ inches provides needed room for table clamps that support rods and apparatus. Tapered or threaded sockets for rods are also often provided in the table top. Wood is the preferred material for physics tables: it is non-magnetic, electrically non-conducting, more quiet than metal, does not dent readily, and resists thermal shock. Solid maple table tops sealed with clear lacquer provide good service. Corrosive chemicals, apart from battery liquids, are seldom used in physics classes. A variety of non-corrosive liquids can be spilled on the table during experiments, however, and the table top should be designed accordingly. The handling of mercury by students is not recommended except under extremely careful supervision because spillage creates an accumulating health hazard and is expensive. Heat experiments in schools seldom require raising the temperature of objects beyond the boiling point of water. Hence, an asbestos pad placed underneath burners, heaters, and containers of hot water usually provides sufficient thermal protection for the table top.

About 7 square feet of table top should be provided for each experimenter. Physics experiments often involve apparatus that spreads out over the table such as tracks, trays, electrical meters and their connecting wires, supporting rods, and swinging pendulums. Ample apparatus room and elbow room should be provided. The top of the table should be kept as free of obstructions as possible. Gas cocks and electrical terminals might well be mounted on the side of the table or, if this is not possible, in compact groups near the center of the table. Incidentally, provide ample storage space against one wall of the laboratory for notebooks and textbooks that are not needed during the laboratory work so that they will not add to the clutter on the table. Hooks in the ceiling above the tables are used in some schools for mounting student apparatus.

The *services* most often required at student tables are gas and alternating current at 120 volts. Currents required at each outlet seldom exceed 5 amperes. At least four convenience outlets for ac and at least one gas connection should be provided for each pair of students. Taps for hot and cold water should be provided at sinks with suitable splashboards, at least two sinks to a laboratory. Direct-current services at several voltages—usually 6, 30, and 120—are needed to varying extents depending upon the level of the physics course. Small direct currents are provided by dry cells, and steady direct current at 6 volts by batteries placed on or near the tables. The higher direct voltages, depending upon the degree of regulation and the power required, are usually supplied by motor-generator sets or rectifier banks. The outputs of these central installations are distributed by panel boards controlled by the teacher or by smaller local power supplies at the students' tables. Central power systems (Figure 4), properly designed and installed,

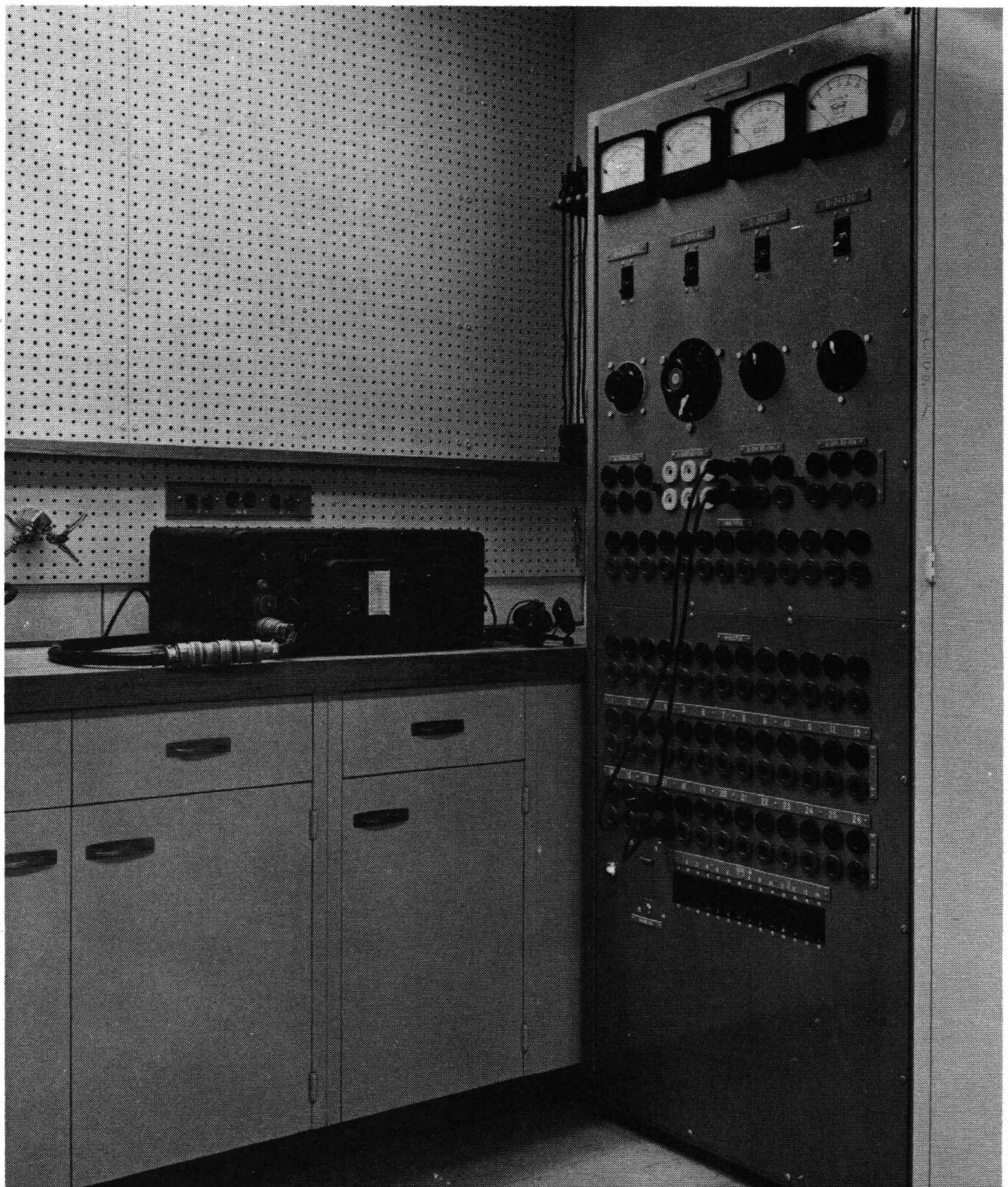


Figure 4. Central power installation using rectifiers for physics laboratory at St. Charles (Illinois) High School. Above the radio receiver is a typical bench outlet.

are versatile, are centrally controllable by the teacher, and generally require a sizable initial investment. However, some teachers prefer local power supplies. While considering the installation of a central switchboard, school planners should look very carefully at the requirements of the school and at the relative advantages and disadvantages to the school of central versus local power supplies with reference to regulation under load, initial costs and maintenance costs, versatility, and student and teacher acceptance of the devices. Some other laboratory services provided in more advanced physics laboratories or project areas in the larger high schools are 6.3 volt ac, rough vacuum lines, and compressed air lines. A good electrical connection to wet ground is useful within the laboratory. If the school has a radio club, conduits from the classroom to the roof will be required for antenna wires. Chemical hoods with exhaust fans are seldom needed in physics laboratories. Students who need them occasionally for projects can usually obtain access to them in chemistry laboratories.

Tables or wall benches should be far enough apart so that students will not bump into each other excessively and so that the teacher can make his usual rounds easily or can quickly get to the scene of an emergency. Clearances where students work back to back should not be less than 5 feet. Sturdy chairs of conventional seat height or sturdy stools about 24 inches high should be provided; rugged construction is called for because students occasionally stand on them to adjust apparatus. Stools whose heights can easily be adjusted are now commercially available. It should be possible to darken the room during experiments on light: opaque window shades sliding in grooves mounted at the edges of the windows or fully-closing venetian blinds are usually employed. Glass panels in doors may require shades. Note that the darkening provided by badly fitted shades or incompletely closed venetian blinds is not sufficient, but on the other hand, the degree of light control required in photographic darkrooms is seldom needed in the physics laboratory. Commercial suppliers of furniture and other fittings for the laboratory can be helpful in providing suggestions and information about their company products. A detached and critical evaluation of their recommendations will enable school planners to obtain maximum educational benefits from expenditures.

So far, we have discussed principally the space requirements for experiments by the entire class. *"Free" laboratory experiments and project work* by smaller groups of students are also important in physics and require, in addition to most of the facilities already discussed, some special facilities. "Free" laboratory experiments require the students to develop their own experimental attack on a problem and in some instances to construct the equipment themselves. The teacher in the free laboratory provides a minimum of detailed instructions and encourages independent thinking and ingenuity on the part of the students. In project work, the emphasis again is upon independent and occasionally original experimentation—the high school counterpart of research. The distinction between free laboratory and project is that the former generally involves shorter experiments performed by teams of two or three students, and the latter involves more ambitious experiments by individuals. Both require more or less secluded space so that equipment can be safely stored or once set up can be left undisturbed until worked upon again. At Garden City (New York) High School, five project booths were built in each physics laboratory. The booths are similar to the fume hoods used in the chemistry laboratory. Each booth is 42 inches wide and 30 inches deep with a lockable door that slides down to the table top. Each booth has two ac electrical outlets, two variable-voltage outlets, and a light. One booth has a gas outlet, and there is a panel of safety glass between adjacent booths. The Bronx High School of Science has separate projects rooms (Figure 5) with lockers for shop equipment and for experimental equipment in physics and chemistry. Rotatable storage cabinets, developed at the Navy Pier

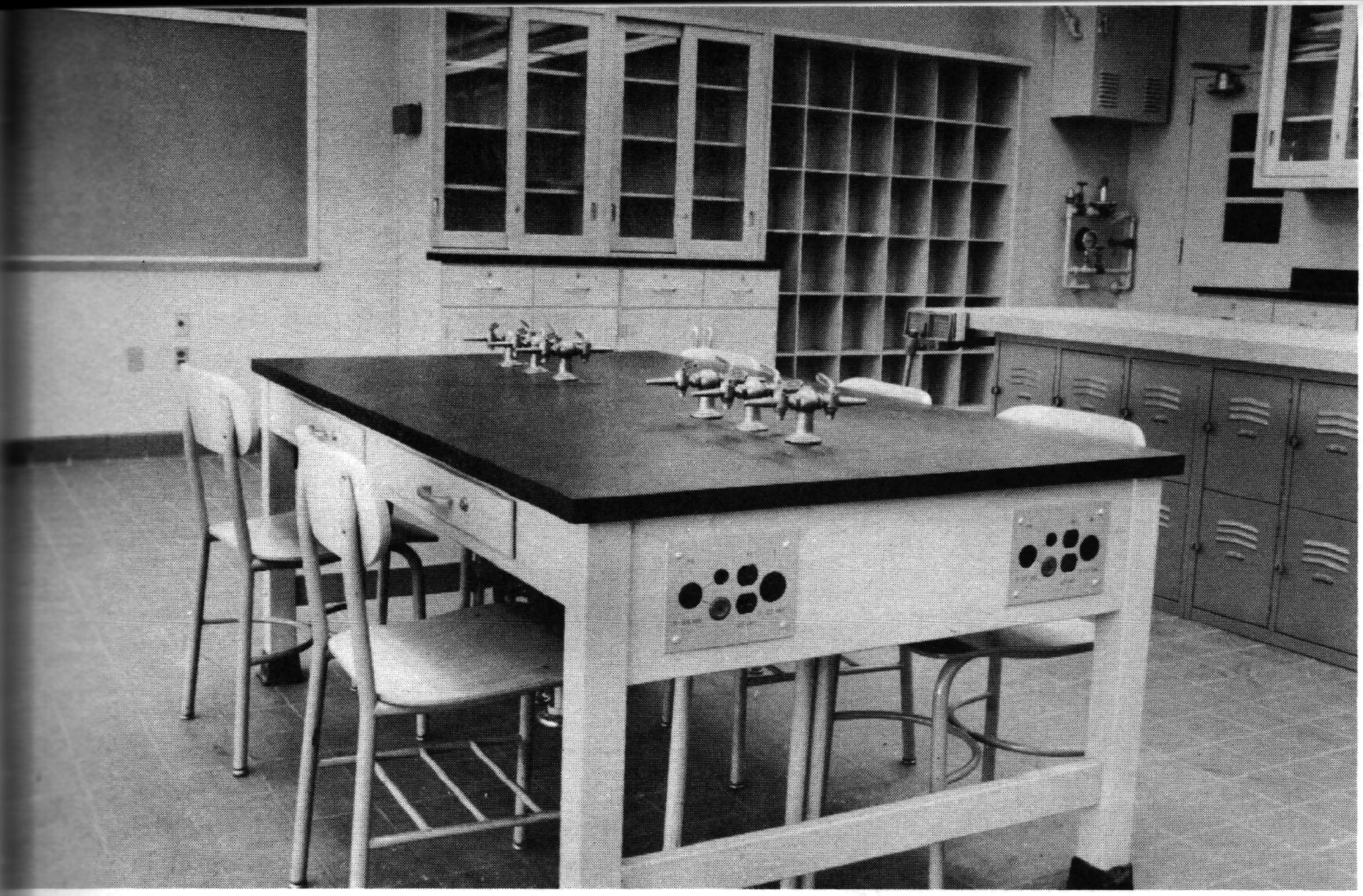


Figure 5. Table for physics projects and for shop work at the Bronx High School of Science. Note the lockers under the work bench at right. Nest of open boxes (in background) provides space for books and notebooks.

Branch of the University of Illinois and now commercially available, offer an ingenious solution to the problem of storing project apparatus (Figure 24 in Chapter 7). In addition to a certain amount of seclusion and a good stock of basic physics equipment, free laboratory areas and project areas require a student work bench with bench tools and simple power tools, a supply of stock materials and parts, and—very important—a reading corner with physics books and journals.

Physics experiments performed in schools are not intrinsically dangerous, but adequate *attention to reasonable safety precautions* in the student laboratory is wise. Electrical fuses or circuit breakers, easily located and replaced or reset, should be placed in supply lines and on delicate experimental equipment. Conservative fuse ratings are recommended to give maximum protection against overload of the lines and of instruments. A central switch to turn off the electrical power at all outlets in the laboratory and a master gas valve to turn off the gas at all stopcocks will provide a certain amount of peace of mind for the physics teacher when he closes the laboratory for the day. By the same token, handles are preferable to knobs on gas stopcocks so that the teacher can see at a glance whether the stopcock is turned on or off. One school has installed a relay switch and "panic" button which the physics teacher can use at his desk to turn off all electric power in the project area in a laboratory emergency. A fire extinguisher of the carbon dioxide type and a fire blanket might be recommended by the local fire marshall. Radioactive materials are handled in such small quantities in school physics laboratories that they do not require special handling other than safe storage. Proper instruction of the students in safe procedures for handling electrical equipment, tools, laboratory burners, and laboratory materials is, of course, the best safety precaution.

Classroom Demonstrations by the Teacher

Demonstrations, in which the teacher performs experiments or illustrates principles with apparatus, are effective in teaching physics. They are not a satisfactory substitute for laboratory experiments by students. However, demonstrations enable the teacher "to present phenomena which lead to principles, to show applications of principles that have already been discussed, to explain the mathematical solution to a problem in physics, to arouse the curiosity of the student, to surprise the superior student and shake his complacency that he knows all there is to know about physics, to inject a humorous note into the discussion, to illustrate how a physicist goes about the solution of a problem, or to summarize and recapitulate a discussion. In their demonstrations, physics teachers should use measuring devices large enough to be seen by the entire class, optical projectors, scale models, standard laboratory apparatus, specially made demonstration devices, and simple home-made equipment."[5]

At present physics demonstrations are rarely given in schools to classes larger than 30 or 40 students. *Larger demonstration classes* can be taught in this way. Colleges have done this routinely for many years. Some schools, as we have noted earlier in the chapter, are now experimenting with lecture sections of over 100 students to whom demonstrations are presented by the most experienced teachers. If the demonstrations can be seen and heard by the entire class—and this requires careful planning—large demonstration lecture classes are feasible. Movable, sound-proof partitions, now under development, will enable schools to provide large rooms for lecture demonstrations and to subdivide this space at another time in the school schedule into smaller rooms for discussion classes and seminars.[8] Inevitably, student-teacher contacts are not as effective in classes of 100 or more as in classes of 30. The give-and-take of discussion between student and teacher is important in physics teaching in probing the student's understanding and in clearing up misconceptions. Provision should be made elsewhere in the school program for these contacts, perhaps in recitation classes or in the laboratory sessions, if demonstration classes are large.

Whatever the size of the class, the physics teacher needs a number of *special facilities* for demonstrations, facilities that are not required in classrooms used for teaching English or American history, for example. The physics demonstrator is a kind of showman and he requires a suitably equipped platform for his demonstrations. The room must be arranged so that the students can see and hear clearly, and various services must be provided for the performance of experiments. Finally, if the room is to be used efficiently, convenient arrangements must be made to move the demonstration apparatus quickly into it from the storage room, to set up the apparatus before the class begins, and to remove the equipment afterwards.

During a class period, a physics teacher who likes to give demonstrations to his students may perform four or five demonstrations, some requiring the use of long tracks, wires stretched between the ends of the demonstration table, and so on. Hence, the *demonstrations table* should be large—about 12 feet long, 3 or 4 feet wide, and approximately 3 feet high (Figure 6). It should be sturdily built of seasoned wood to support heavy equipment and to serve as a firm base for experiments. The table is usually enclosed in front and on the sides. Cabinets and drawers are provided at the back—the teacher's side of the table—for storage of vacuum pumps and other accessory apparatus used in demonstrations. The top of the table is painted with a corrosion-resistant paint and overhangs the sides by 2½ inches or more to permit the use of clamps. Four or five flush plates—sockets for tapered or threaded table rods—are set into the table top for mounting apparatus. A small sink with hot and cold water taps and a drain should be installed near one end of the table, recessed and provided with a cover that fits flush with the table top. Two or three gas cocks with hose nozzles should be distributed along the back of the table, preferably under the overhang or in some other unobtrusive place so that the teacher and students will not bump into them. Convenience outlets for 120-volt ac should be provided in generous numbers, at least a half dozen at the back, two on each side, and two on the front of the table. If a central direct-

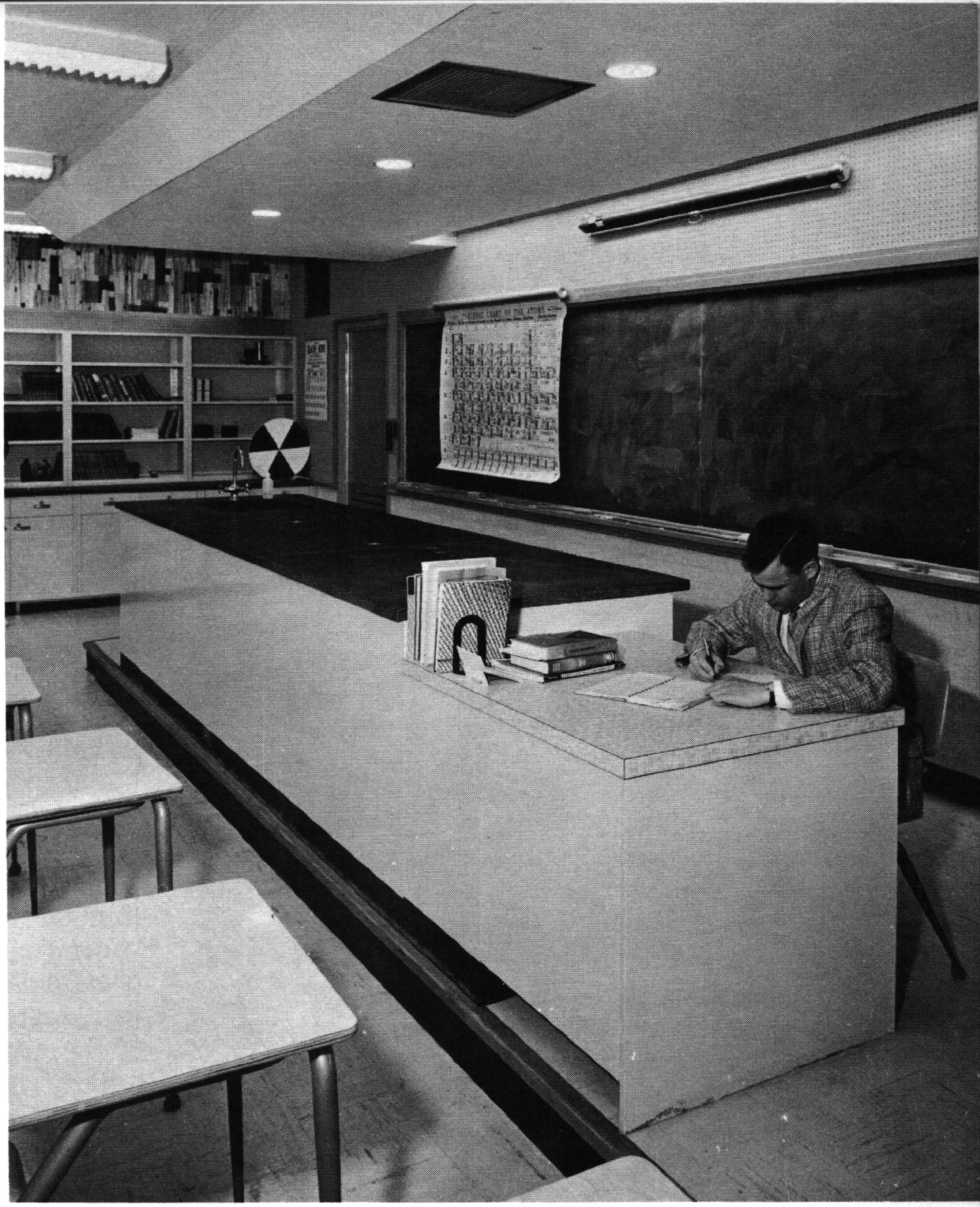


Figure 6. Demonstration table and teacher's desk at St. Charles (Illinois) High School.

current supply is planned for, several lines from the dc switchboard to the demonstrations table should be provided. If not, the teacher will use local dc power supplies or batteries, which can be conveniently installed in the demonstration table. Compressed-air service is a convenience, but not essential. Shielded cables connecting the lecture table to a loud speaker or to a mirror galvanometer mounted at the ceiling near the middle of the room are wanted by some teachers. Large "station meters," ammeters and voltmeters mounted on the wall, are provided in some schools as demonstration equipment. Lines connect the meters to the lecture bench so that the demonstrator can select the right ranges and insert the meters into circuits at will.

The *surroundings of the demonstrations table* will have much to do with whether it is effectively used. The students sit in front of the table, separated from it by a clear space 4 or 5 feet in depth. This cleared area allows the teacher to walk around to the front of the table in performing some experiments and to suspend apparatus occasionally—pendulums, long springs, and so on—from the ceiling in front of the table. Tablet-arm chairs of sturdy

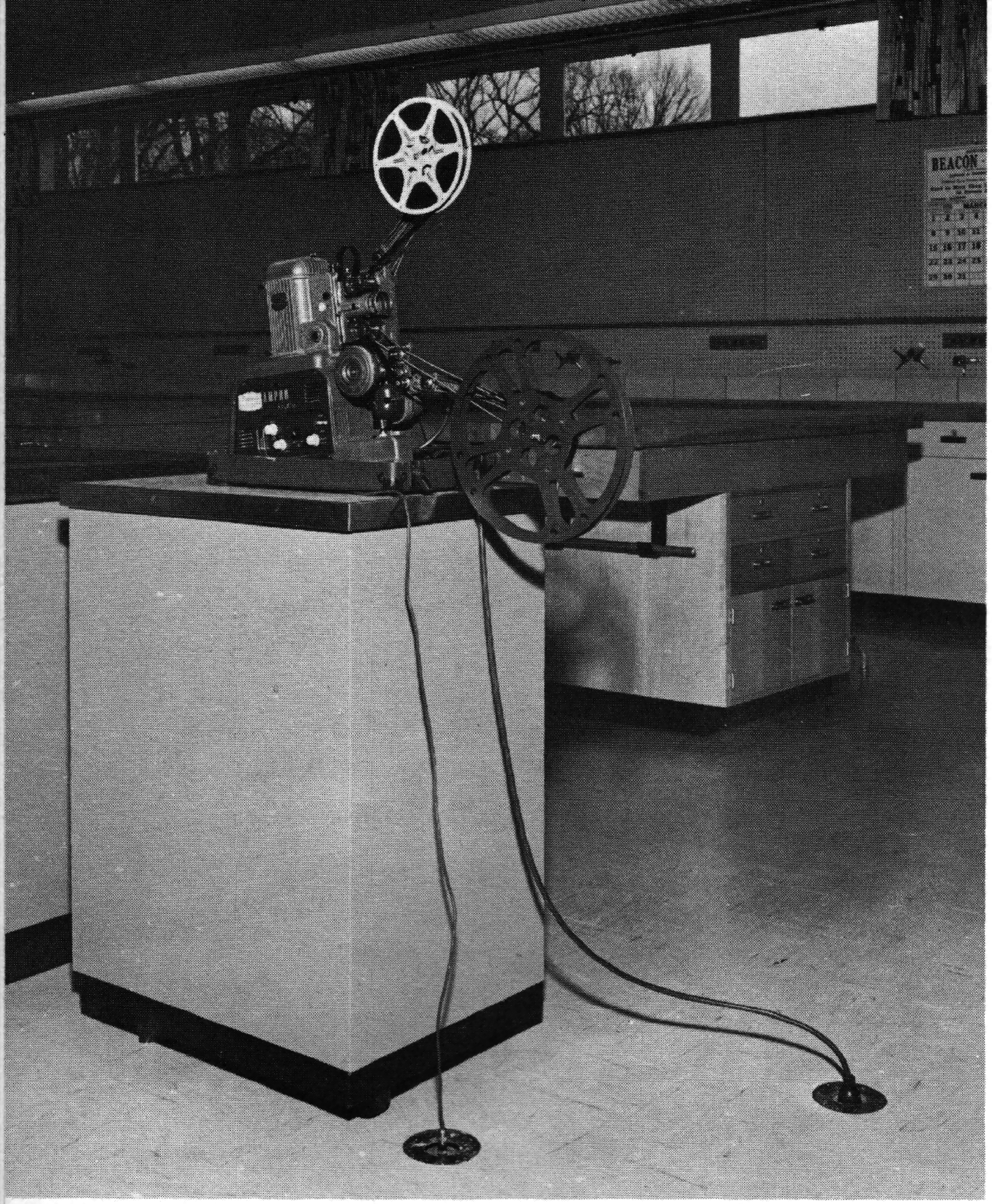


Figure 7. Projection table and floor outlets at St. Charles (Illinois) High School. Note laboratory tables in background.

construction with ledges for books under the seat are ordinarily provided for the students. Chairs with both seats and backs of Fiberglas, which has been color-impregnated, have proven to be completely serviceable at St. Charles (Illinois) High School; maintenance costs are lower because scratches do not show so readily. Some schools have the students sit at laboratory tables, but this causes difficulties if apparatus for laboratory experiments has been set up. Hooks or a rail on the ceiling over the demonstration table or over the space in front of it and channels inserted into the walls will permit the mounting of apparatus.

Ensuring that the demonstrations can be seen and heard by *every* student is extremely important (see Chapter 5), particularly as class sizes grow. Clear sight lines, provision of adequate supplementary illumination at the demonstration table and chalkboard, and the avoidance of glare must be carefully considered by the building planners. In addition, the physics teacher must review every demonstration from the viewpoint of his students and make a deliberate attempt to see that apparatus is large enough, that scales are visible, that contrasting colors are used in painting apparatus, and so on. Approximately 12 lineal feet of chalkboard behind the demonstration table is required. Slate chalkboards are preferable as a writing surface, but the more colorful steel-base chalkboards have the advantage of being magnetic so that pointers, cardboard and plastic aids to visualization, and other light objects can be attached to them with small alnico magnets during demonstrations. A projection screen for audio-visual aids and for the shadow projection of apparatus should be provided over the chalkboard or on a side wall. Electrical connections for projectors should be provided—a shielded cable under the floor with appropriate outlets at the front and back of the room for sound and ac convenience outlets at the back of the room for the projector (Figure 7). Charts are occasionally used during physics classes and means should be provided for mounting them at the front of the room—a chart rail or tack strip over the chalkboard. Peg boards are being installed increasingly in physics classrooms and laboratories for mounting booklets, posters, tools, and apparatus inexpensively and attractively.

Light control is important in many physics demonstrations and for audio-visual aids. The room should be provided with light-tight shades, and at least one set of switches for the room lights should be within easy reach of the demonstrator, preferably at the back of the demonstration bench, so that the teacher can easily darken the room.

Television will be used increasingly as an adjunct to teacher demonstration in physics in the future. Difficult or dangerous experiments, interviews with famous physicists, and activities within physics research laboratories will be witnessed by physics classes by television either in live programs or by videotape, in broadcast programs or by closed circuit. How to equip central television studios in schools and provide lines for distributing the video and audio signals to classrooms falls outside the scope of this book. Here we will merely note that the television receiver may well be accessory apparatus in the physics demonstration room of the future. Sight lines for viewing the receiver in a variety of classroom situations have been studied, and considerable information about ways of mounting receivers is available for school planners.[4]

We close these notes about demonstrations in physics by pointing to the possibilities of *corridor exhibits*—"demonstrations to individuals." Some of the larger high schools (Figure 8) are finding corridor exhibits valuable as a means of reinforcing student understanding of certain of the ideas of physics and arousing interest in physics among students in the earlier grades. The corridor exhibits contain apparatus, materials, charts, clippings, and explanatory labels. They are displayed in locked cabinets built into the corridor wall near the physics laboratory and are replaced periodically by the physics teacher.

Discussion and Recitation

Discussion and recitation in physics courses have already been mentioned as providing the give-and-take exchanges between student and teacher that clear up difficulties and lead to greater understanding of the breadth and the subtlety of physics concepts. The demands upon the skill and knowledge of the teacher are large, but the facilities required are rather modest—tablet-arm chairs for the students, around 20 lineal feet of chalkboard so that the class can be sent to the board in two "shifts" to solve physics problems, a table and chair for the teacher, and a bulletin board for posting classroom notices (Figure 9).

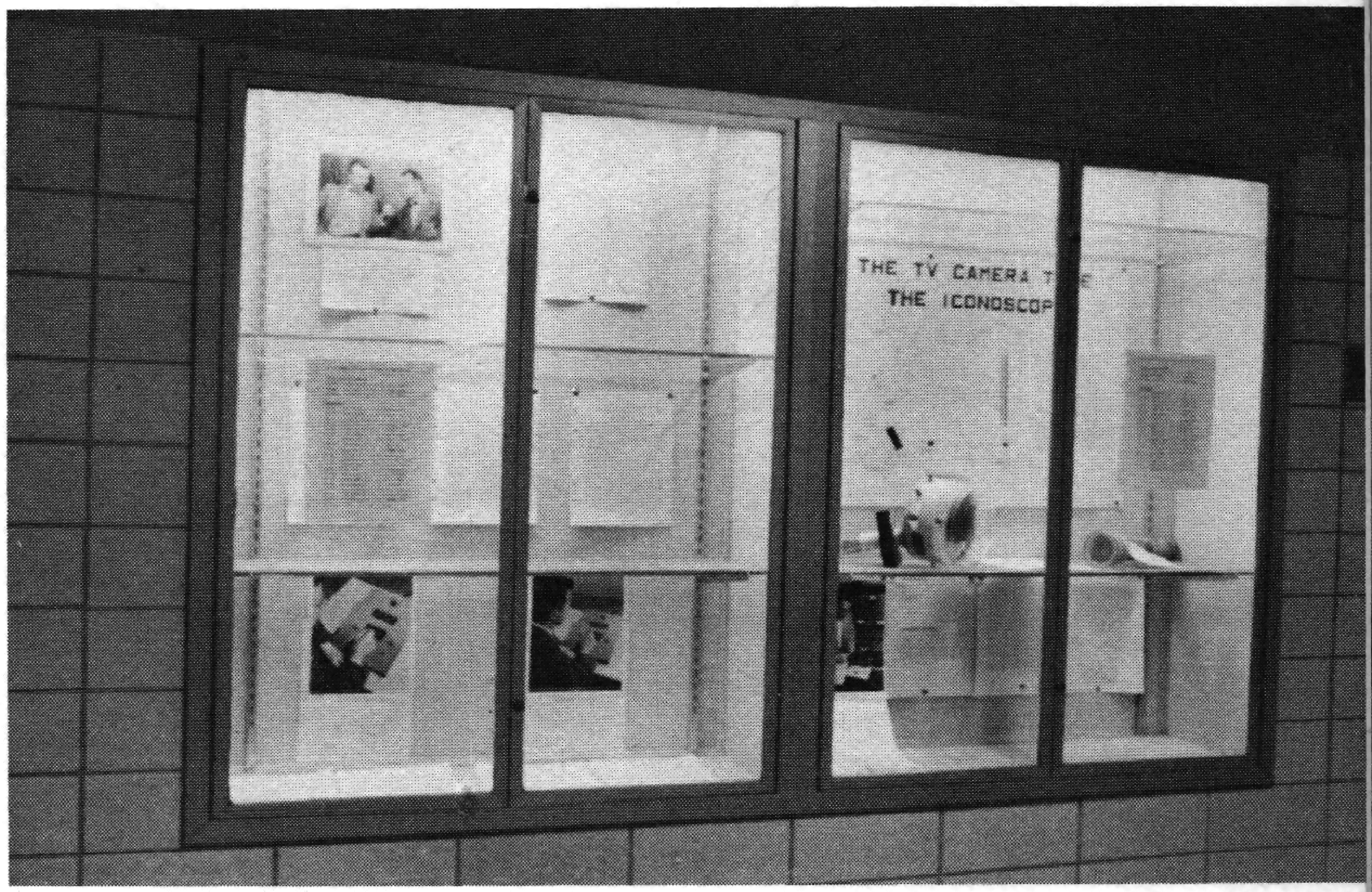
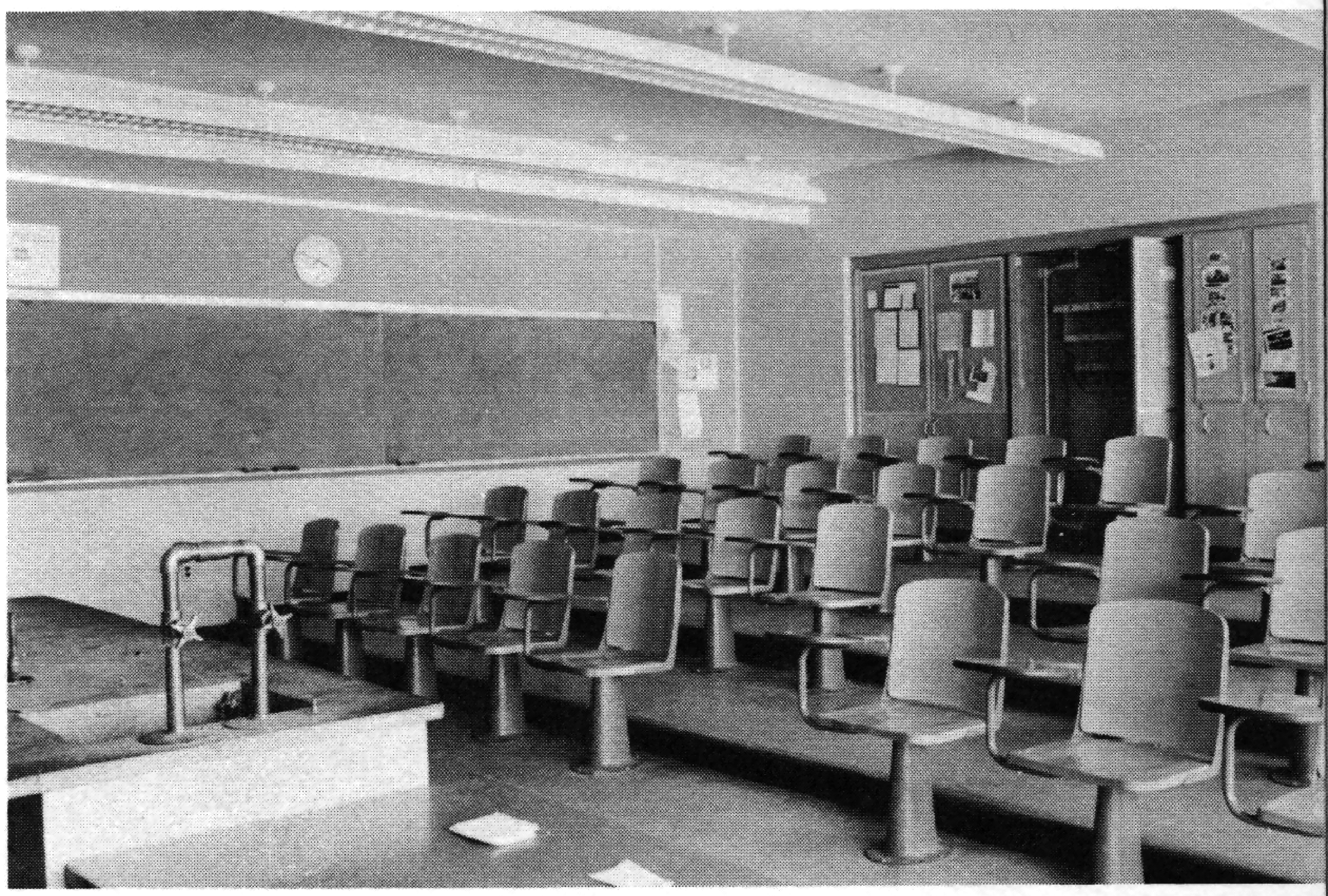


Figure 8. A physics display cabinet in the corridor wall at Bronx High School of Science.

Figure 9. Medium-size classroom (40 seats) for discussion sections in physics at Bronx High School of Science. Note coatracks and tack boards at back of room. The demonstration table was added at front to permit demonstrations if desired.



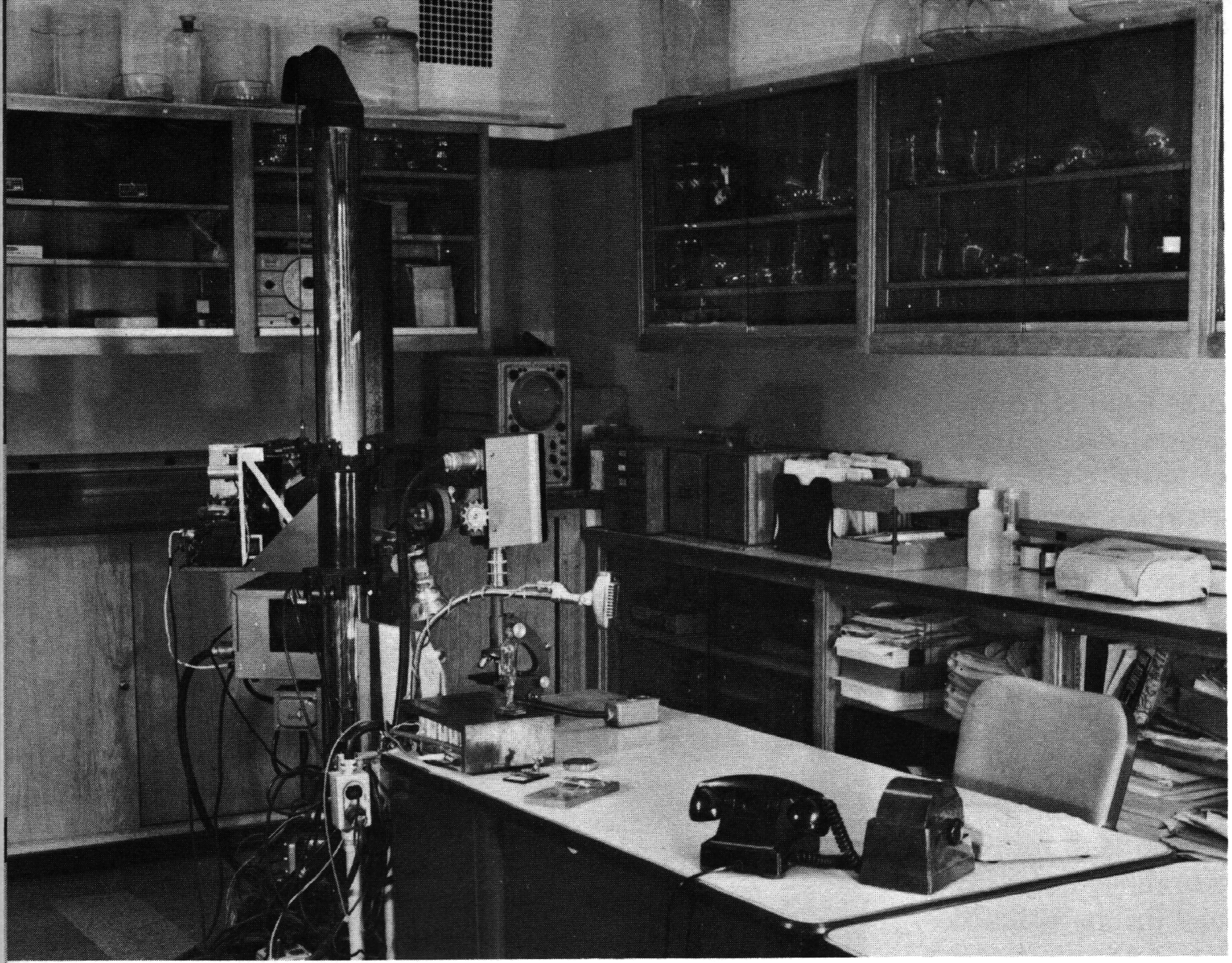


Figure 10. Office adjacent to the science project area at Evanston (Illinois) High School has additional space for storage of apparatus and a small research area for the teacher. Equipment at left is a closed-circuit television system used with a microscope as a microprojector in biology. Note the "panic" button and cord on desk used for turning off power in project area in an emergency.

Office Work

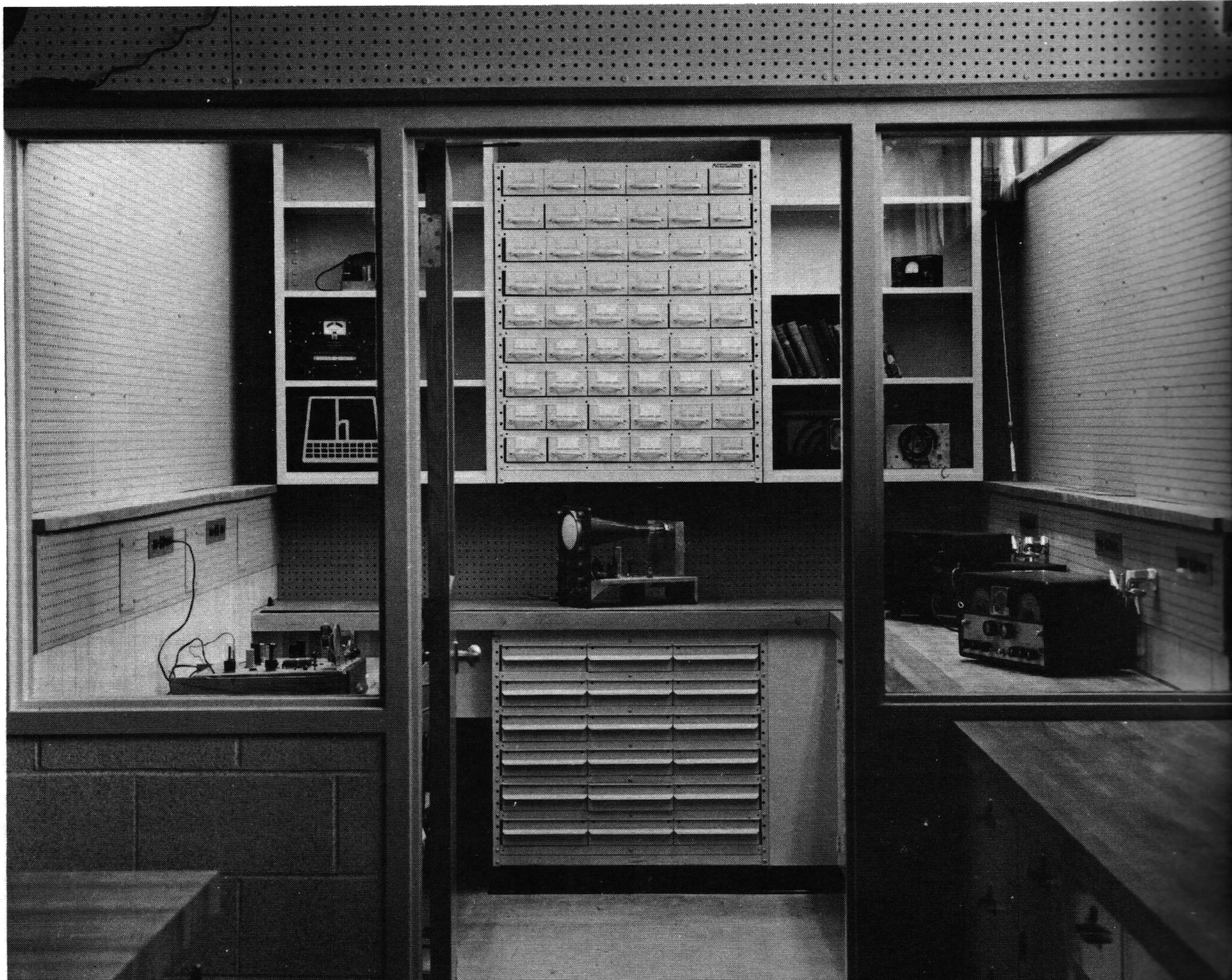
Grading, planning, conferences with students, and running the laboratory in the physics course require that the physics teacher have a quiet and comfortable place to work when he is not instructing students (Figure 10). A desk and comfortable chair of his own and a book shelf or bookcase would seem to be an absolute minimum of equipment. In addition, a four-drawer filing cabinet with a lock is recommended for storing the innumerable papers, booklets, catalogs, and leaflets that any science teacher needs to conduct the laboratory and to keep up with his field. The teacher's desk should be as close to the physics classroom and laboratory as possible. In some schools, teachers with physics teaching assignments may have their desks in the preparations-storage area or in a room used as the departmental office. A desk for the teacher in the classroom-laboratory is more common. Every effort should be made to provide a reasonably quiet and private place so that the physics teacher can grade papers and reports, plan lessons and laboratory work, confer with students about difficulties or about special projects, and carry on the ordering of laboratory equipment and supplies.

Storage of Apparatus

The storage and maintenance of apparatus and supplies in physics deserve the careful attention of school planners if the physics program is to be fully effective. Physics teaching, as we have emphasized in the foregoing discussion, requires apparatus, laboratory materials, small parts, and stock materials in fairly large quantities and in great variety. As contrasted with chemistry and biology, physics relies heavily on what is essentially capital equipment—meters, oscilloscopes, timers, calorimeters, and so on—rather than on consumable supplies. Consumables are needed in physics, but generally the physics teacher can use equipment for year after year. If the equipment is originally of good quality and is carefully maintained, the school's investment can be protected and the stock of equipment built up by yearly additions.

The problem of *storing equipment* includes providing enough shelf and cabinet space, locating the storage space conveniently near the places where the apparatus will be used, protecting the stored apparatus against damage or loss by suitable covers and locks, and providing a convenient organizational scheme so that the physics teacher can find apparatus and materials quickly (Figure 11). Approximately 150 square feet of shelf space are needed for storing most of the student laboratory equipment in schools where there are 24 students in a physics laboratory class; locked cabinets along the walls of the laboratory serve well for this purpose. The preparation room should have an *additional* 300 square feet of shelf space as well as numerous drawers for apparatus and supplies. All cabinets should have doors, locks, and adjustable shelves; narrow shelves should be avoided, particularly in cabinets equipped

Figure 11. Storage for electronics parts and equipment, and work area at St. Charles (Illinois) High School.



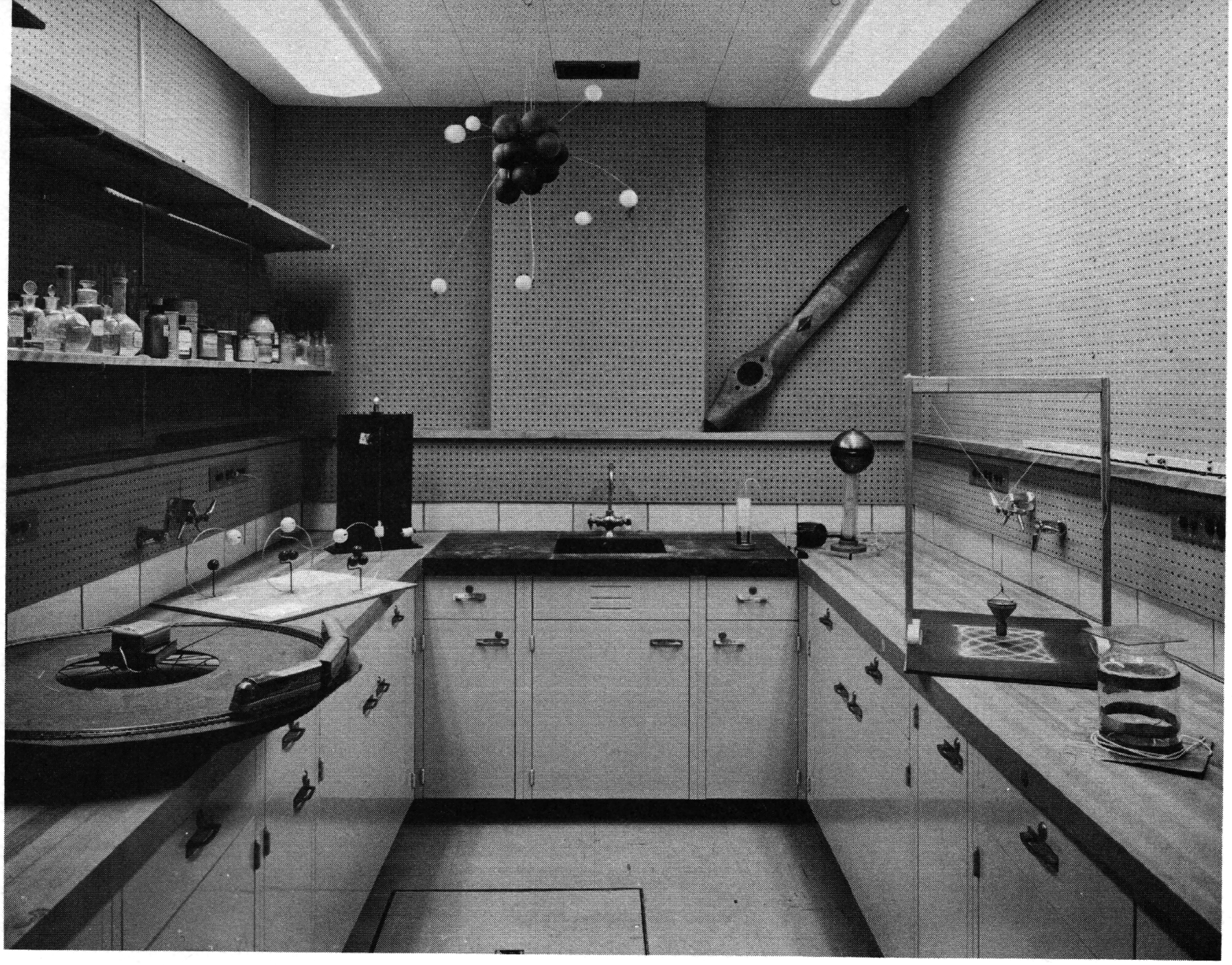


Figure 12. Physics preparation area at St. Charles (Illinois) High School.

with sliding doors. Chemicals and batteries should be stored at a distance from the other materials in a well-ventilated place from which corrosive fumes will not reach apparatus. In one school, the door that leads from the storage area to the classroom-laboratory is a Dutch door with a counter mounted on the lower half so that equipment can be checked out at the door. Audio-visual equipment preferably should be stored on the spot where it will be used. We have already remarked that the cabinets in the base of the demonstration table can be used for storing some equipment accessory to the demonstrations—vacuum pumps, power supplies, clamps, and so on. Many physics teachers follow the scheme of organizing their storage space according to the subdivisions of the physics course, assigning some cabinets to mechanics equipment, some to light, some to electricity and magnetism, and so on. A card file of equipment and supplies, kept up to date, is essential.

The *preparation area* is usually combined with the storage room. Preparations include the preliminary setting up of apparatus to be used in demonstrations and student laboratory experiments, repair and maintenance of apparatus, construction of new apparatus, and occasionally photographic development. The preparation area should be equipped at least with a strong table and may well contain a table or bench fully equipped with a sink and the services supplied to the laboratory tables (Figure 12). If a workbench is not conveniently nearby in the student laboratory, the preparation area should have a workbench. Some schools provide means of darkening the preparation-storage room so that it can be used as a photographic darkroom. (Large schools that have photography clubs provide separate darkrooms that can be used by the science departments.) To facilitate the setting up of demonstrations in the classroom and their removal after class, rolling tables of the same height as the demonstration table are used in many schools: the apparatus is set up in the preparation area and the tables are wheeled into the classroom shortly before the class begins. The tables on wheels are not a complete answer to the problem of full utilization of the demonstrations classroom, however. Many demonstrations require on-the-spot setting up, so that the classroom must be free during the period before the demonstrations are to be given.

FOR EARLY CONSIDERATION

Programming

Preparing functional specifications for the space to be used by physics classes will of course be only a part of the problem of programming the entire school building. (See Chapter 2 on Programming.) Nevertheless, early in these discussions the architect, who often devotes half of his design effort to programming, will want the views of the school administration and the teaching staff concerning the science facilities. We cannot stress too strongly the importance of consulting the physics teacher. He has had the experience of working in the present physics laboratory, and he is in direct contact with the problems of teaching physics within the complex of conditions represented by the school, the students, and the community. The viewpoint of the teacher cannot be dispensed with if the physics rooms are to be properly designed for the school. Involve him early and often in the planning process. Physicists at nearby colleges, universities, and industrial laboratories, who have had experience in planning laboratory facilities, can also be helpful and should be called in as consultants. Visits to successfully functioning physics laboratories in other nearby schools are also very much in order.

An excellent introduction to the problems of school construction and valuable background information on costs, planning, and structural details will be found in *The Cost of a Schoolhouse,* published by the Educational Facilities Laboratories, Inc.[8]

Location

The location of the physics space is not critical. If the school is to have a science wing, physics classrooms naturally will be in it and can share certain facilities with the other sciences—a shop, project room, science library, and photographic dark room. However, a southerly location on the ground floor, once recommended for physics laboratories, is no longer essential. Physics laboratory sessions are occasionally noisy, however, and it is well to keep this in mind in assigning academic neighbors. It would be convenient, but not essential, for the physics area to be located near the school shop.

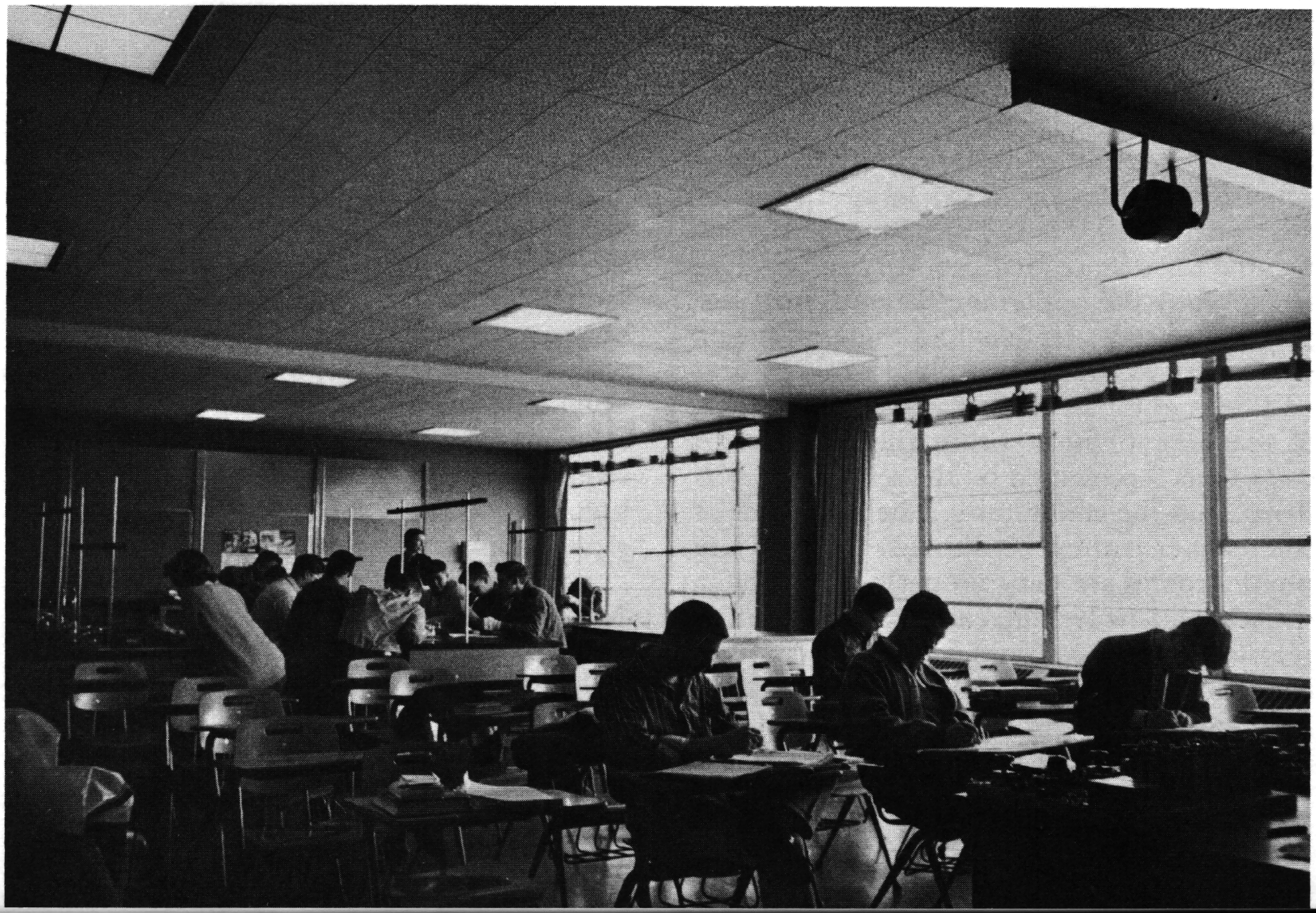
Combination Rooms

Combinations of physics areas with those used for other subjects have to be considered in the smaller schools. Physics and chemistry are the two subjects most often combined in this way although physics and general science sometimes share a laboratory-classroom. The severe requirements of construction economy and full utilization of space often understandably necessitate such arrangements. However, the growing enrollments in all of the sciences, including physics, make it imperative that the possibility of the future need for separate laboratories for the different sciences not be overlooked in planning new schools. Moreover, the kinds of activities described here as characteristic of physics classes—and this is also true of chemistry and the other sciences—can be best carried out in a room devoted to physics, a room that is a headquarters and a home for physics students and teachers. However well planned, arrangements for sharing a classroom tend to destroy the characteristic "atmosphere" that develops in a room long used for hard and serious study of a science. Less important, but still something to consider, are the practical difficulties of sharing—extra moving of apparatus by teachers to make way for incoming classes in the other subjects and the effect of fumes from the chemistry experiments upon stored physics apparatus. Nevertheless, the sharing of classrooms by several sciences is thought to be desirable or necessary by many schools, and we shall give examples of such arrangements later in this chapter. Another kind of combination is the use of the same room for both laboratory work and demonstration-discussion classes—the laboratory-classroom. This is a common and advantageous arrangement in small and medium-size schools (Figure 13) because it allows the teacher to plan a flexible program of student experiments and class discussion within the same room. Large schools, however, often have separate demonstration-discussion rooms and laboratories because this arrangement places a strong emphasis on laboratory work which might otherwise be slighted in favour of teacher demonstrations.

Size

The size of physics rooms depends of course upon the class size. We have referred earlier to a slow trend toward a more flexible policy concerning class size in schools. Large demonstration classes and smaller seminar and laboratory classes are to be expected in the future. Currently, the average physics room provides between 40 and 50 square feet per student for a class of 24 students plus about 250 square feet for storage and preparation. Thus we are talking about an area of roughly 1200 square feet for one classroom-laboratory

Figure 13. Combination classroom-laboratory for physics at Garden City (New York) High School. The demonstration table (right foreground) faces tablet-arm chairs. Project booths, laboratory tables and benches are at rear of room. The average class size is about 24 students.



unit in physics. We suggest, however, that any average space estimates of this kind not be taken too seriously. The total space requirements for physics in a particular school should evolve from the programming discussions mentioned previously. Twelve hundred square feet devoted to physics might be lavish for one school program and grossly inadequate for another. Moreover, whether the room is used for physics alone or for physics and some other subject must be considered in deciding upon the size.

Shape

The shape of the physics room is not critical except that rooms should not be excessively long and narrow if they are to be used for teacher demonstrations. The problem of making demonstrations visible is too difficult in long rooms regardless of whether the demonstration table faces the long dimension or the short one. A more nearly square room or square area is preferable for demonstrations.

Ventilation, Lighting, and Acoustics

Ventilation, lighting, and acoustics in the physics room, with certain exceptions, generally do not require special measures for adequate levels of control. Ventilation requirements recommended by the several states[9] average about 3 to 4 complete changes of air per hour in laboratories where chemical fumes are not produced, and up to 9 changes of outside air per hour in chemistry laboratories. General illumination should be between 30 and 50 foot-candles. Additional illumination, up to a total of 70 foot-candles (see Chapter 5) may be needed on the demonstration table. In some schools windows are placed high on the walls so that the wall area beneath them can be used for mounting apparatus and so that sunlight does not produce glare on shiny surfaces in the room. Freedom from glare and sharp contrasts and the use of attractively colored paints, wall tiles, and floor coverings are most important. The use of washable paints reduces maintenance costs. Acoustical treatment of physics classrooms and laboratories is strongly recommended. A suspended ceiling which combines lighting and acoustical panels on a modular grid may be worth considering.

Utilization

Utilization of physics rooms requires careful interpretation. Occupancy of the room by classes every school period is one possible—and common—definition of full utilization. Such use may not produce the best educational results, however, if it bars the physics teacher from setting up needed demonstrations or prevents project work in the physics laboratory. Currently, around 80% class occupancy of the physics laboratory is about the maximum that can be expected considering schedule difficulties and the need for set-up time and projects. When sound-proof and flexible partitions at moderate cost become widely available, the utilization of the large and expensive classroom areas can approach 100% because the smaller specialized areas such as the demonstration table, project areas, and so on, can be temporarily closed off with partitions. Encouraging progress is being made in developing flexible, adequately soundproof partitions for school use. An acoustical curtain of metal filament interwoven with other fibers, now under development[8] may prove to be the flexible divider long sought for.

Flexibility

Flexibility in physics classrooms includes not only the ability to subdivide the space with sound-proof, easily moved partitions, but also provision for the addition of services as teaching requirements change. For example, it is a defensible practice to install gas and water pipes and electrical conduit in exposed parallel runs wherever possible. The advantages in installation, use, and maintenance of exposed service lines outweigh the dust problem. When installing service lines, provide spare plugged tees in the water and gas lines and spare junction boxes in the electrical conduits to provide for extra work stations in the laboratory or to convert a classroom into a laboratory at some future time. A recent trend in industrial laboratory and shop furniture may offer some advantages of flexibility in school physics rooms. Piping, valves, and electrical outlets are confined to the service strip rigidly fastened to the perimeter wall of the room. Except for the sinks, all furniture is completely free to be rearranged as the room occupants wish. Patent metal struts are available commercially that can be attached to walls and that permit shelves or table tops to be easily set up at desired heights.

Floor Coverings

The floor coverings currently most used in physics laboratories are vinyl tile and asphalt tile.

Table Top Materials

Table top materials (see Chapter III), listed in order of increasing cost, include:

1. Solid wood top, laminated, lacquered, or oil finished (for general use)
2. Pressed wood fiber such as Masonite
3. Solid hardwood, such as birch or maple, laminated with resinous finish
4. Cement asbestos surface such as Transite (heat resistant—for glass-blowing benches)
5. Plastic sheet such as Formica, Panelyte, or Textolite
6. Solid natural stone with baked resinous finish
7. Stainless steel sheet (for photographic darkroom benches whenever a high degree of cleanliness is required)

Sinks

Sinks and cup sinks (see Chapter III), listed in order of increasing cost, are available in several materials:

1. Porcelain on metal base
2. Acid-resistant silicon iron alloy such as Duriron or Corosiron
3. Soapstone, or Alberene stone
4. Moulded or welded plastic such as polyvinyl chloride, polyethylene, Fiberglas with resin
5. Stainless steel, pressed or welded
6. Pyrex glass

Most sinks are available integral with tops of the same material. Costs are generally reduced, however, by installing the sink separately on the job in a cut-out in the top. Patent rims and jointing compounds have reduced the problems of field installation, but should be compared for tightness and for the amount of rim obstruction which each presents; many are far from flush.

SOME EXAMPLES OF PHYSICS ROOMS IN HIGH SCHOOLS

A. The classroom-laboratory in physics

George E. Thompson (Illinois) High School (Figure 14 a, b, c)
East Orange (New Jersey) High School (Figure 15 a, b, c, d)
Westmoor (California) High School (Figure 16)

B. The physics-chemistry room

Death Valley (California) Union High School (Figure 17 a, b, c)
Darien (Connecticut) High School (Figure 18)

C. Separate classrooms and laboratories

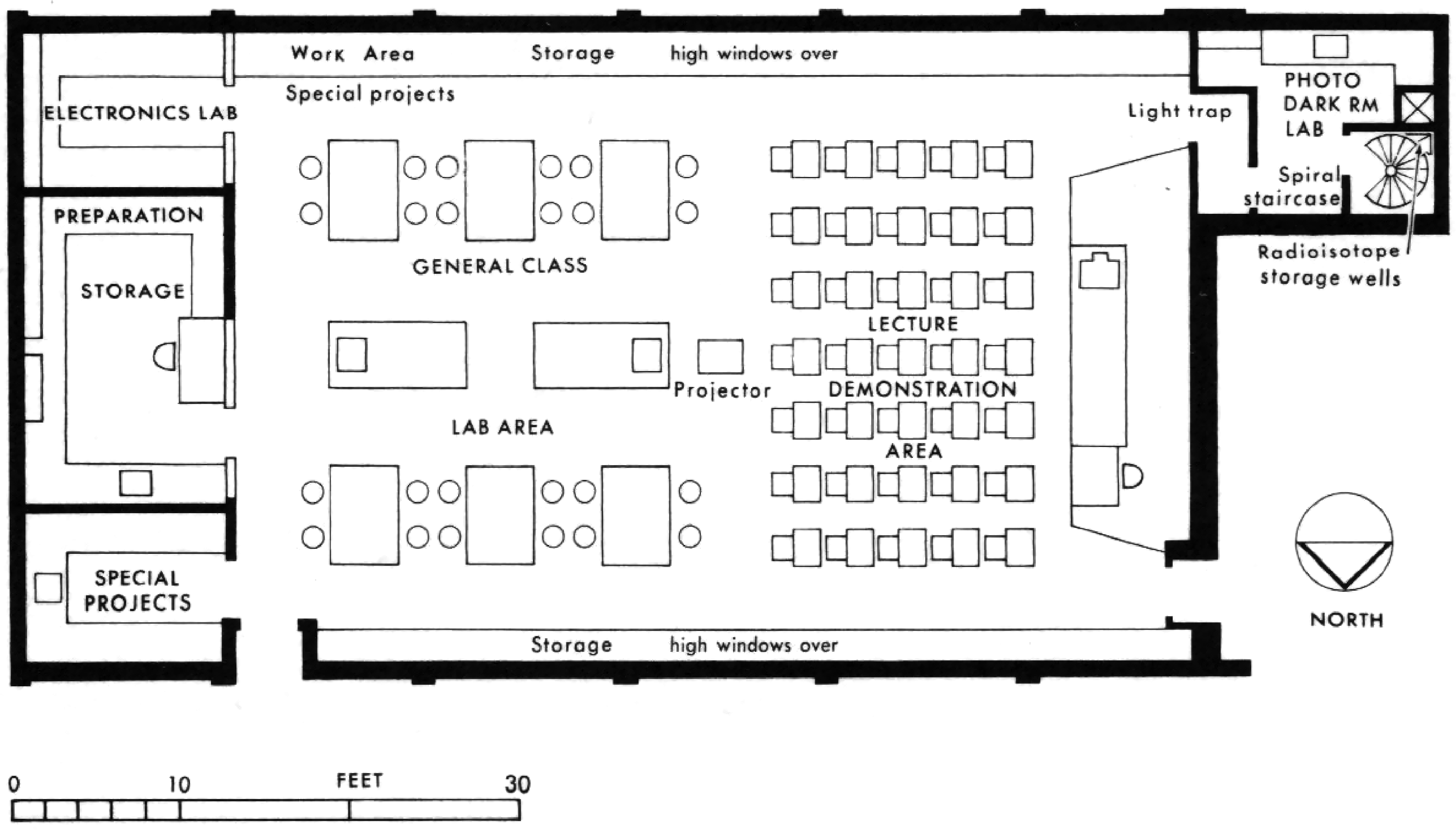
Bronx High School of Science (New York) (Figure 19 a, b, c, d, e, f)

D. The science project room

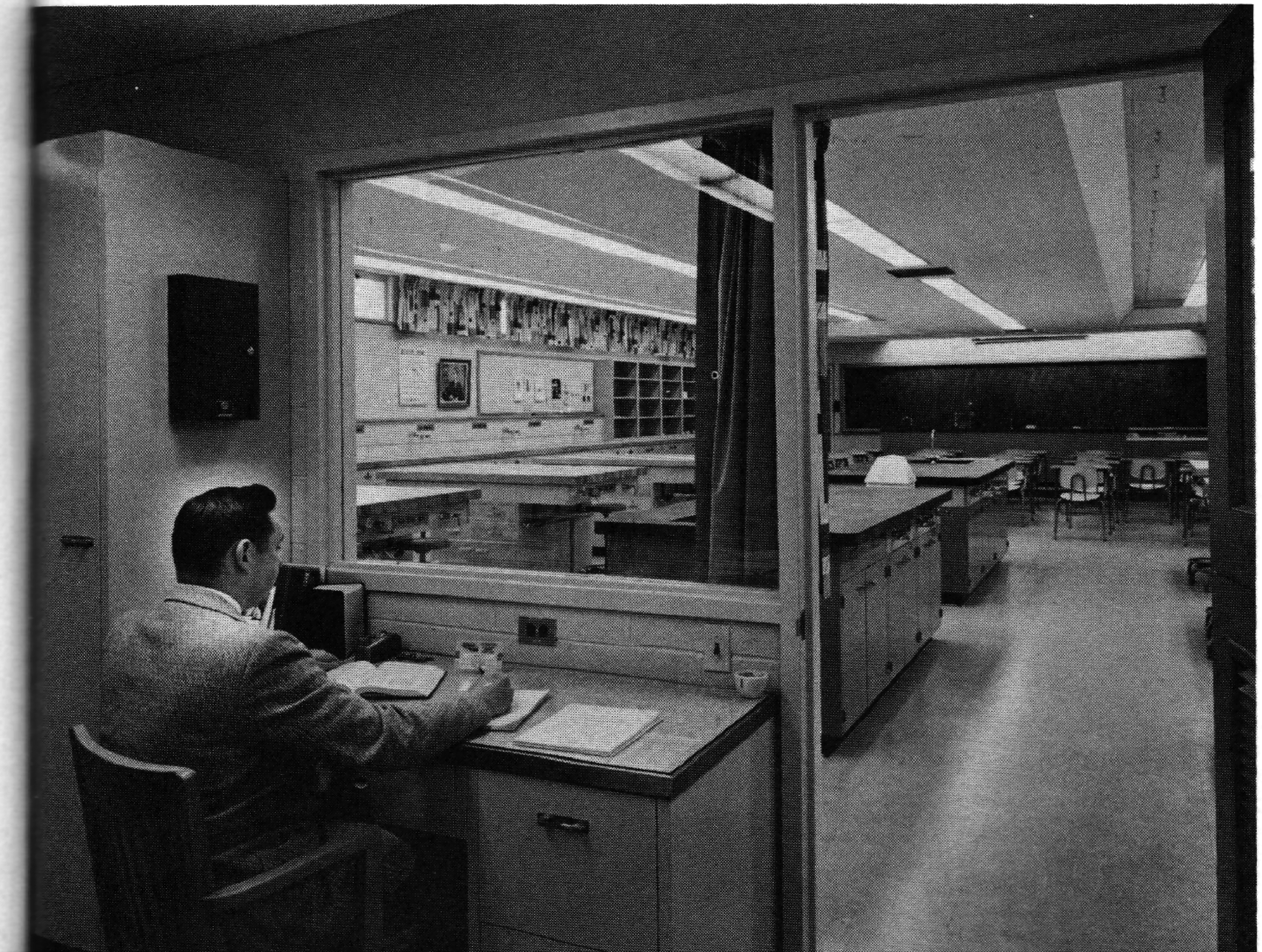
Evanston (Illinois) High School (Figure 20 a, b, c)

The classroom-laboratory in physics

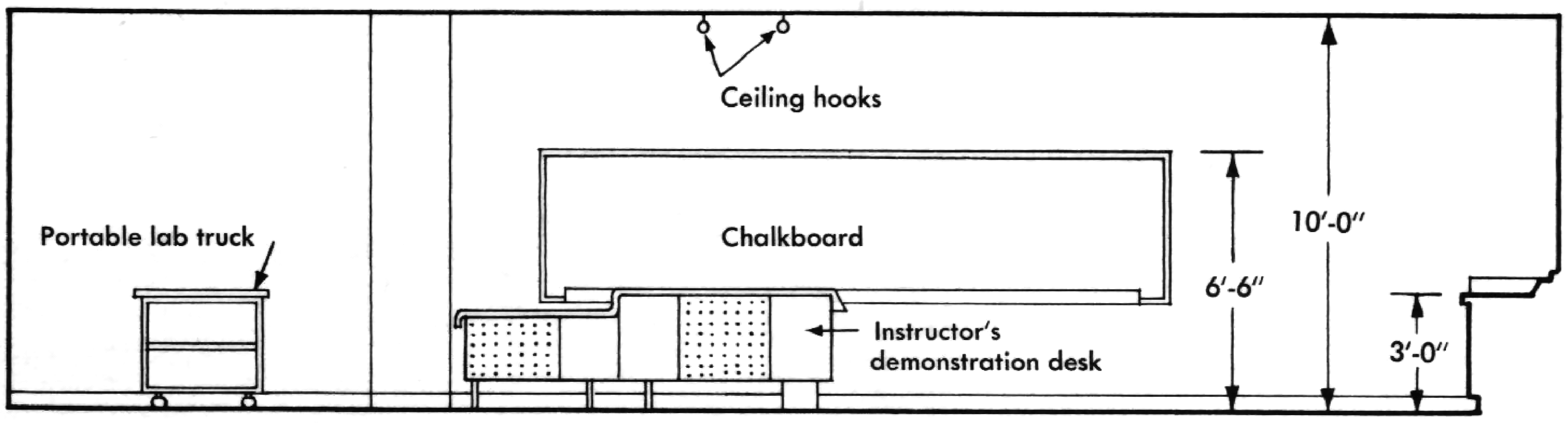
Figure 14. Floor plan of physics laboratory in Science Wing of George E. Thompson High School, St. Charles, Illinois. Nicol and Nicol, Architects, St. Charles.


Work Area
Storage
high windows over
Special projects
ELECTRONICS LAB
PREPARATION
STORAGE
GENERAL CLASS
LAB AREA
Projector
LECTURE
DEMONSTRATION
AREA
Light trap
PHOTO
DARK RM
LAB
Spiral
staircase
Radioisotope
storage wells
SPECIAL
PROJECTS
Storage
high windows over
NORTH
0
10
FEET
30

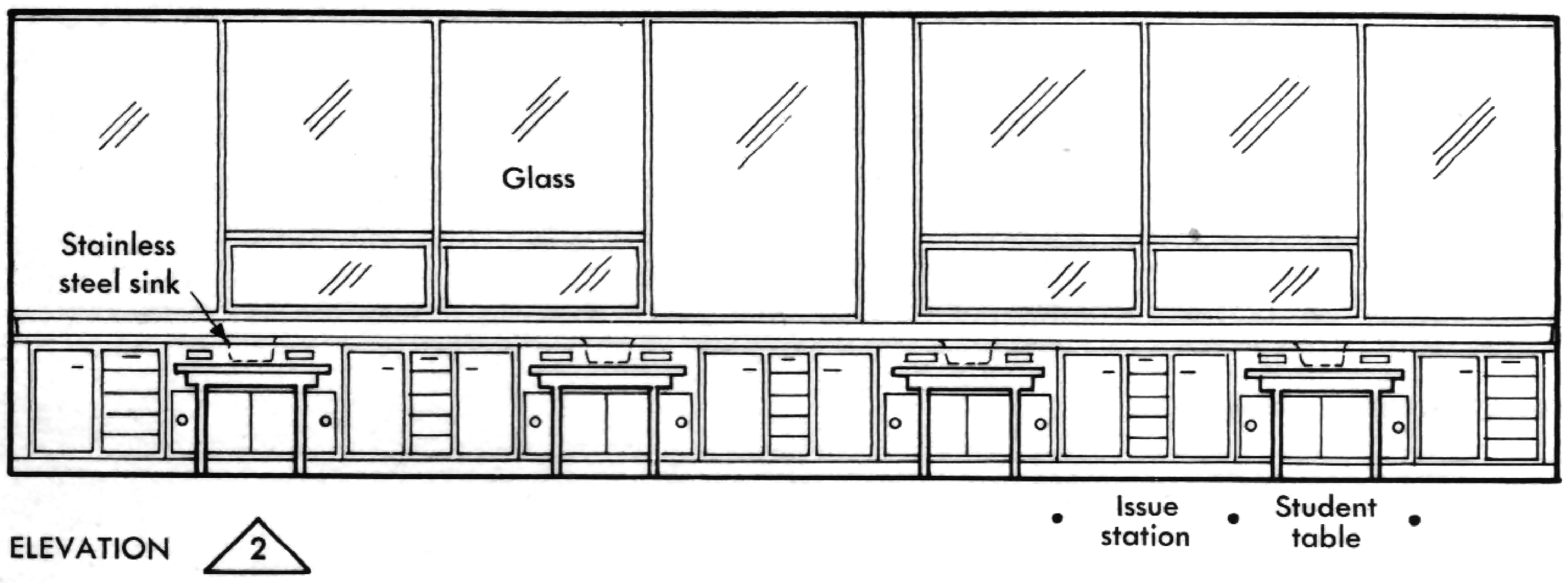
Work area showing high windows which permit more efficient use of wall beneath. Hooks are installed throughout entire ceiling of the laboratory to facilitate the performance of experiments.



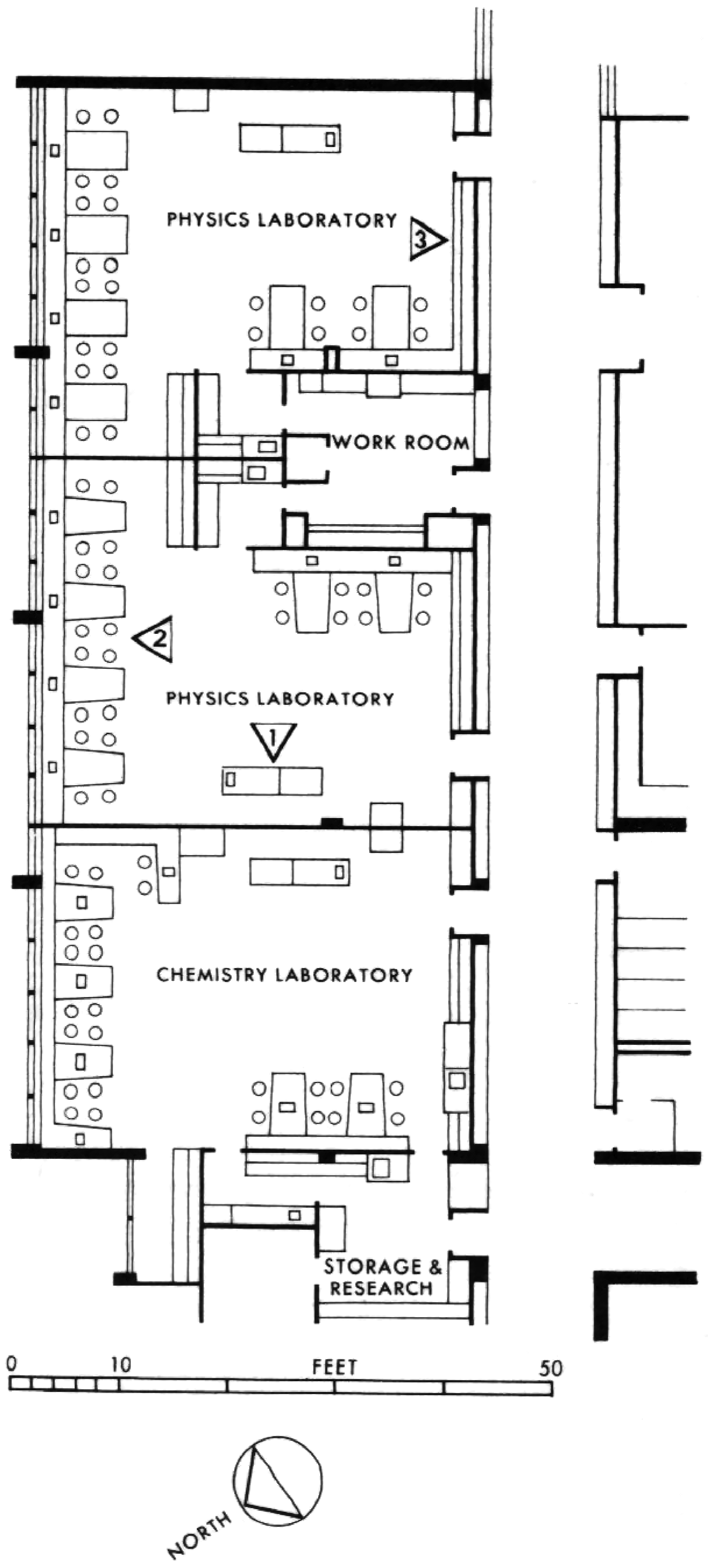
Instructor's office, looking into classroom. Flexibility is provided by separate functional areas for lecture, laboratory, and project work.

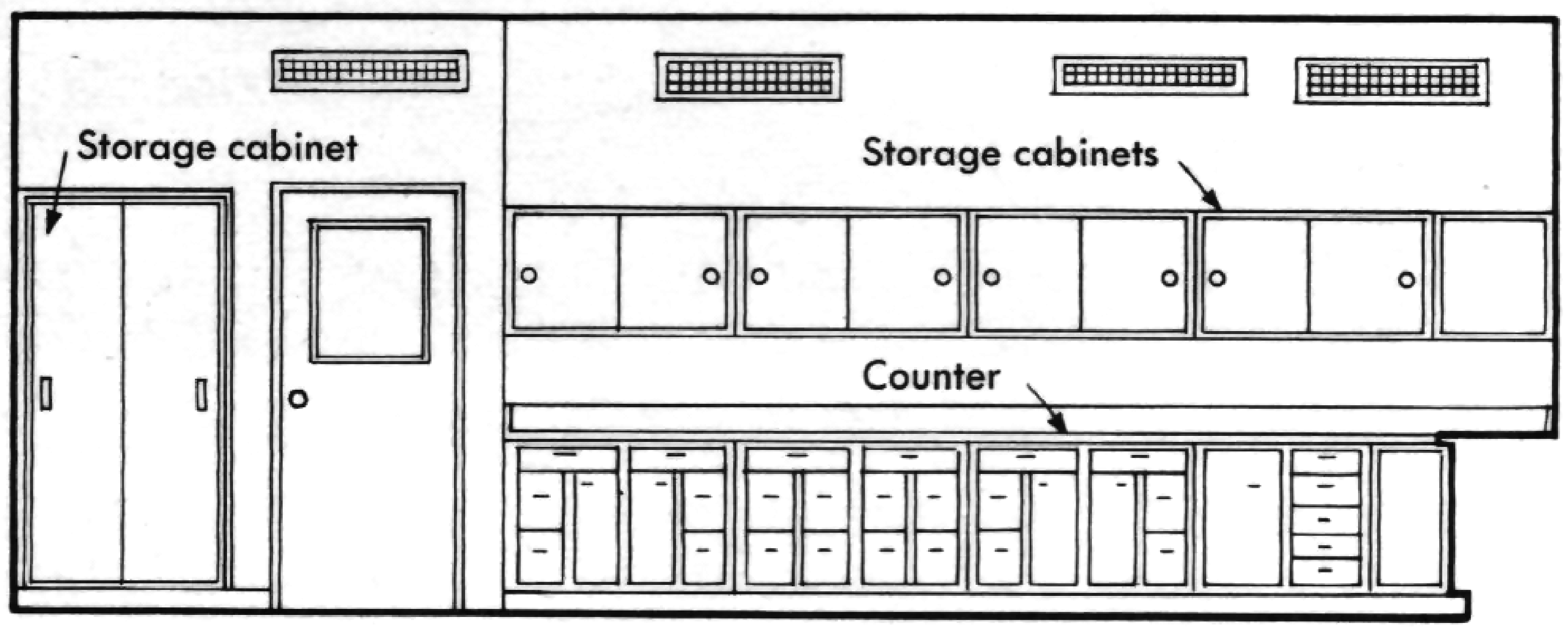

Ceiling hooks
Portable lab truck
Chalkboard
10′-0″
6′-6″
3′-0″
Instructor's demonstration desk

ELEVATION 1


Glass
Stainless steel sink
Issue station
Student table

ELEVATION 2


PHYSICS LABORATORY
3
WORK ROOM
2
PHYSICS LABORATORY
1
CHEMISTRY LABORATORY
STORAGE & RESEARCH
0
10
FEET
50
NORTH


Storage cabinet
Storage cabinets
Counter

ELEVATION 3

Figure 15. Floor plan of Physics and Chemistry Wing and three strip elevations of physics laboratory, East Orange High School, East Orange, New Jersey. Emil A. Schmidlin, Architect, East Orange. Point of view for each elevation is shown on plan.

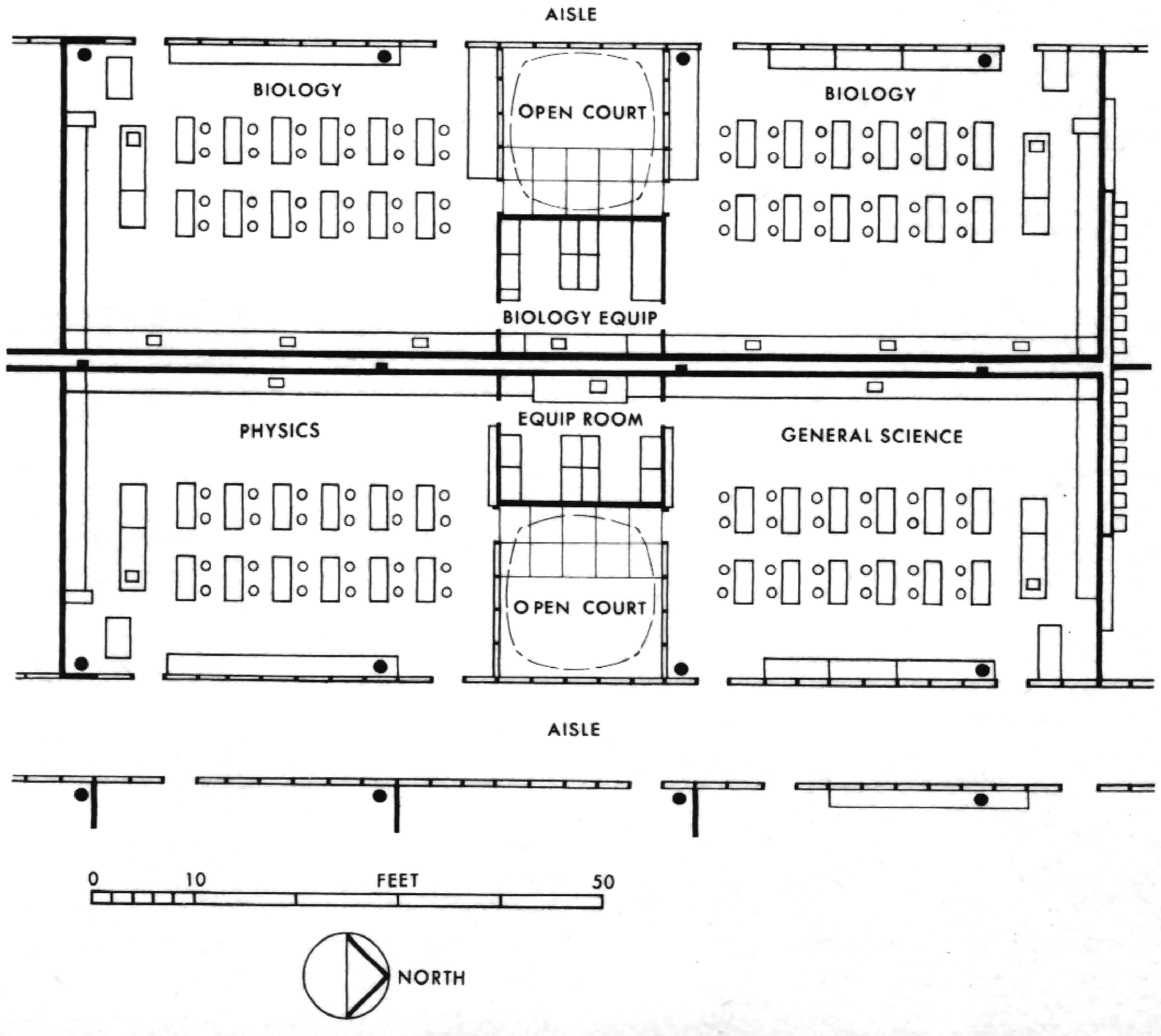

AISLE
BIOLOGY
OPEN COURT
BIOLOGY
BIOLOGY EQUIP
PHYSICS
EQUIP ROOM
GENERAL SCIENCE
OPEN COURT
AISLE
0
10
FEET
50
NORTH

Figure 16. Floor plan of Science Wing, Westmoor High School, Daly City, California. Mario Ciampi, Architect, San Francisco.

The physics-chemistry room

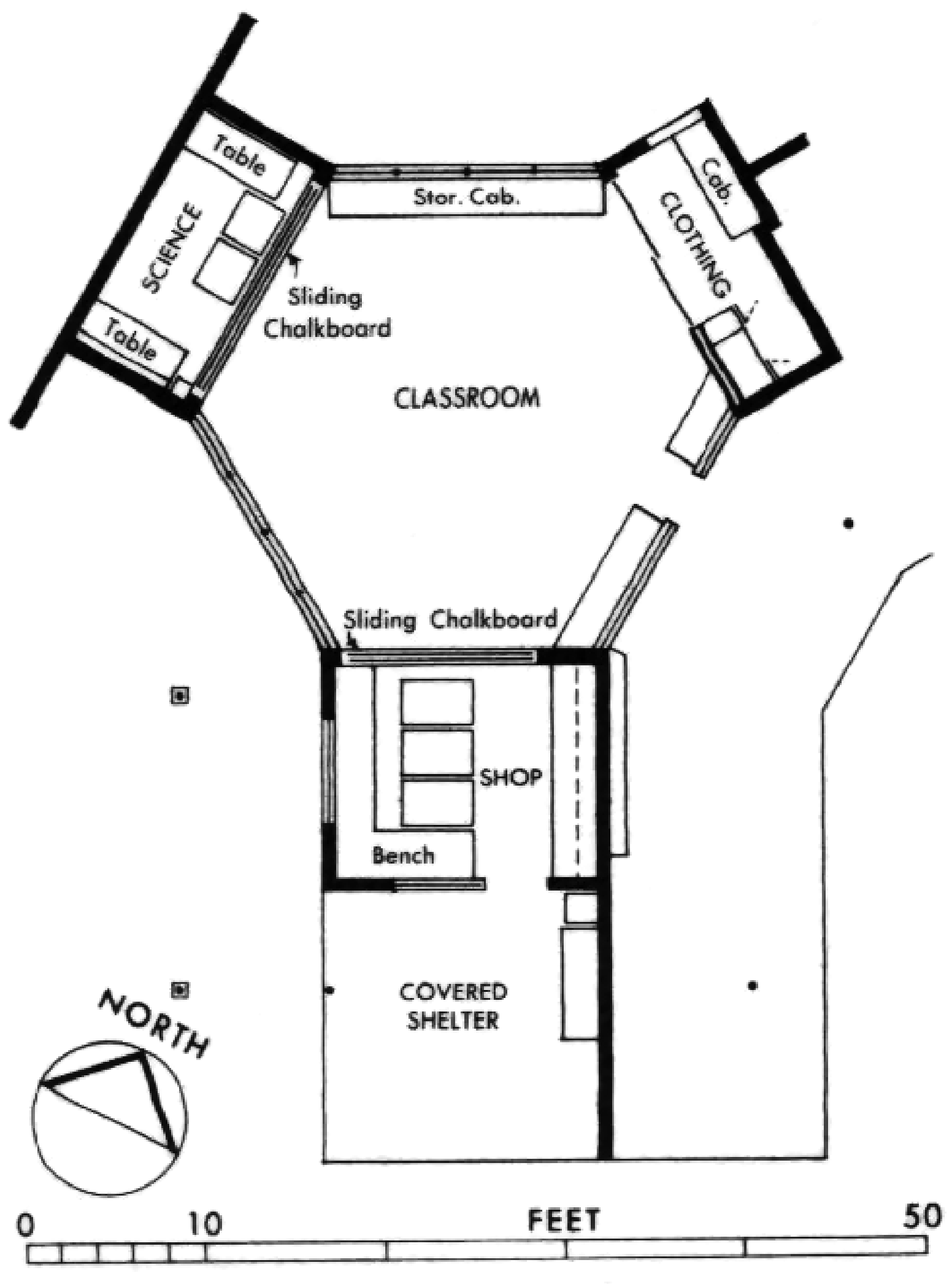
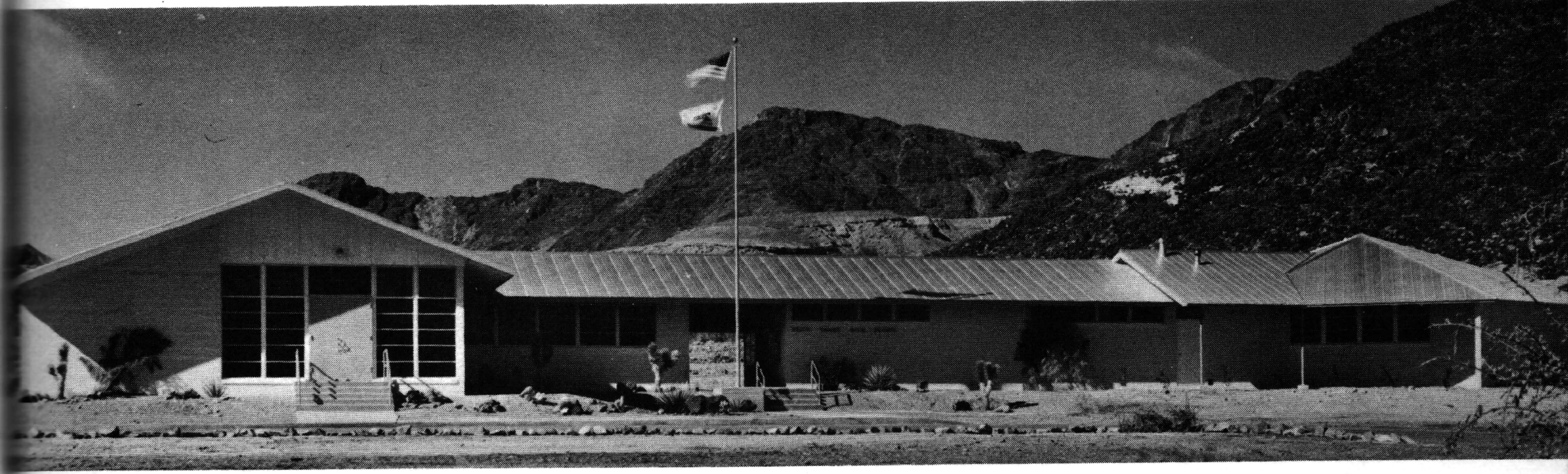
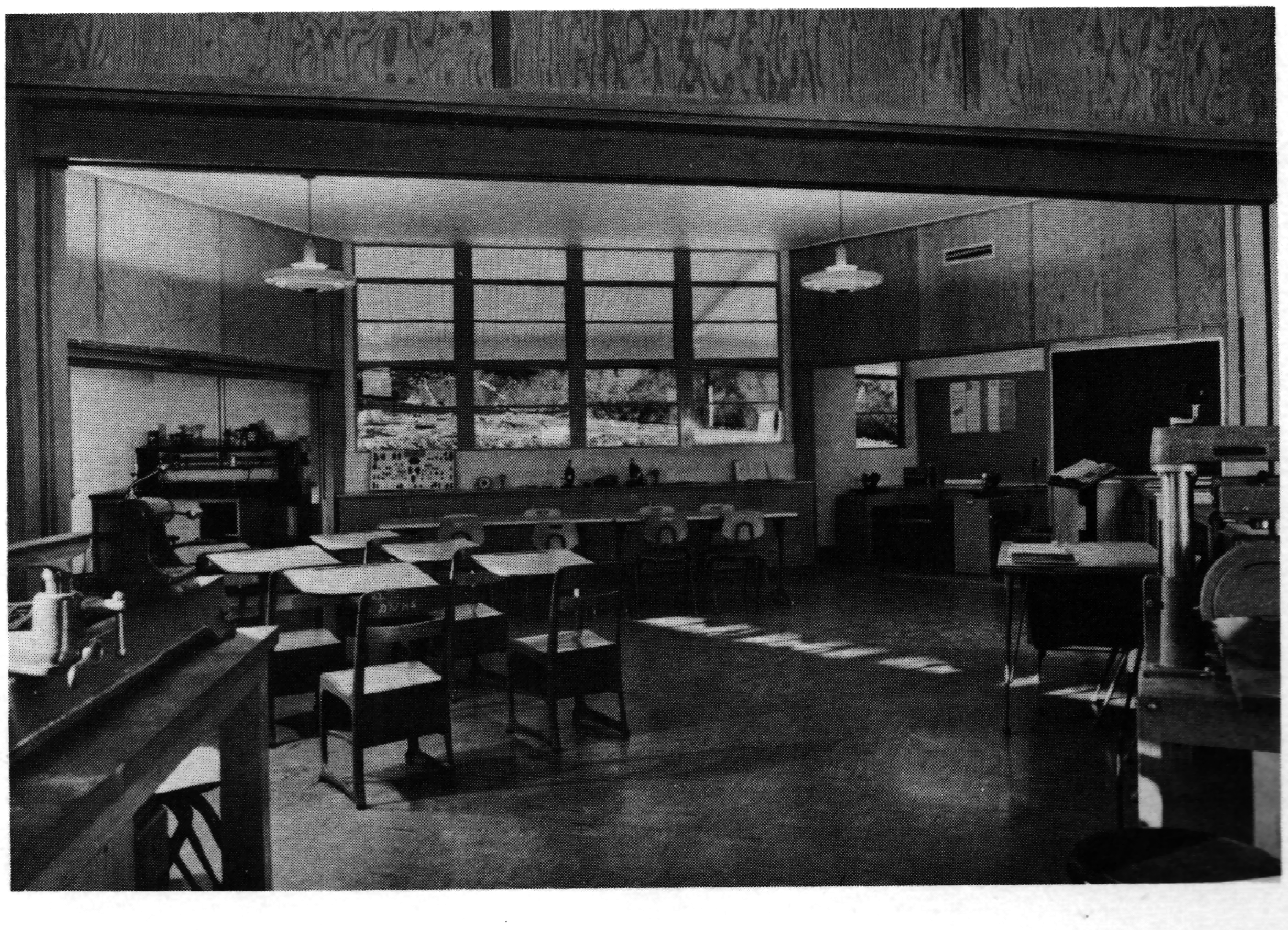


Table
SCIENCE
Table
Stor. Cab.
Cab.
CLOTHING
Sliding Chalkboard
CLASSROOM
Sliding Chalkboard
SHOP
Bench
COVERED SHELTER
NORTH
0
10
FEET
50

Figure 17. Floor plan of Death Valley High School, Shoshone, Inyo County, California, showing classroom with adjoining alcoves for science, clothing (domestic science), and shop. This is a small school with 3 teachers and a student enrollment of 21. Note that flexible arrangement of a common classroom and alcoves for special equipment permits fuller utilization of space. The alcoves can be closed by means of the sliding blackboards. Robert Trask Cox, Architect, Los Angeles.



Exterior of school building.



Science area viewed from shop through open sliding chalkboard.

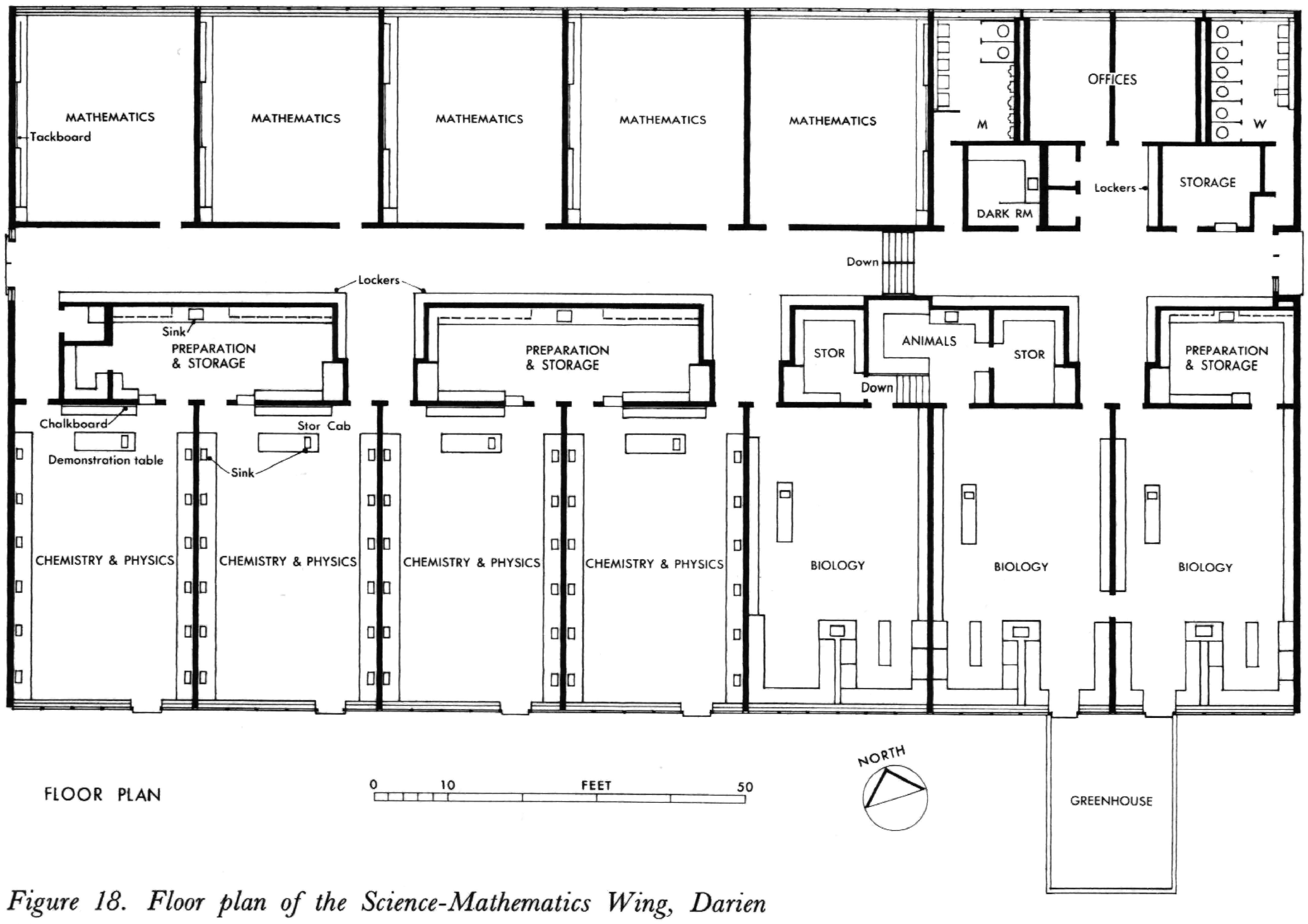
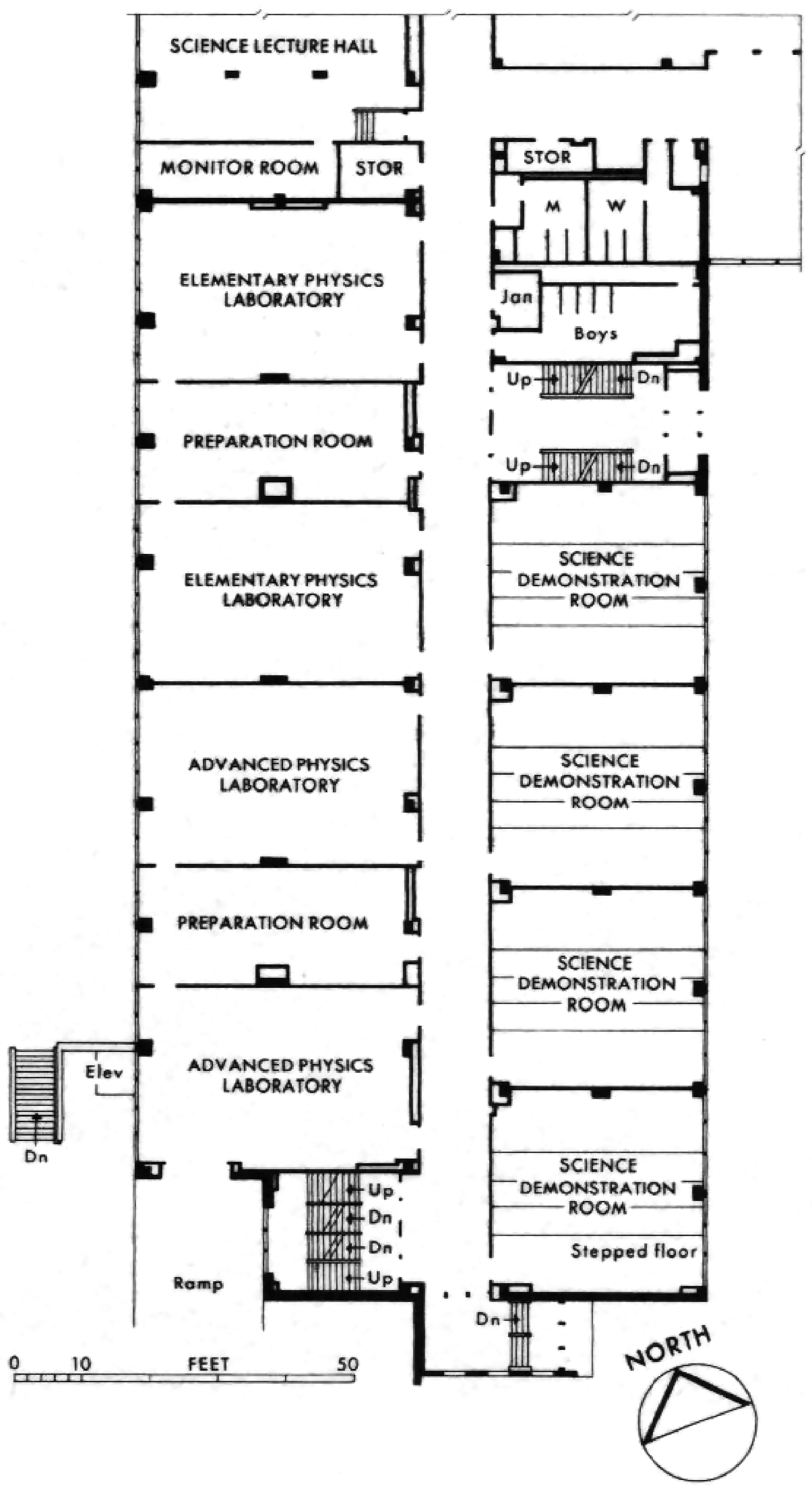
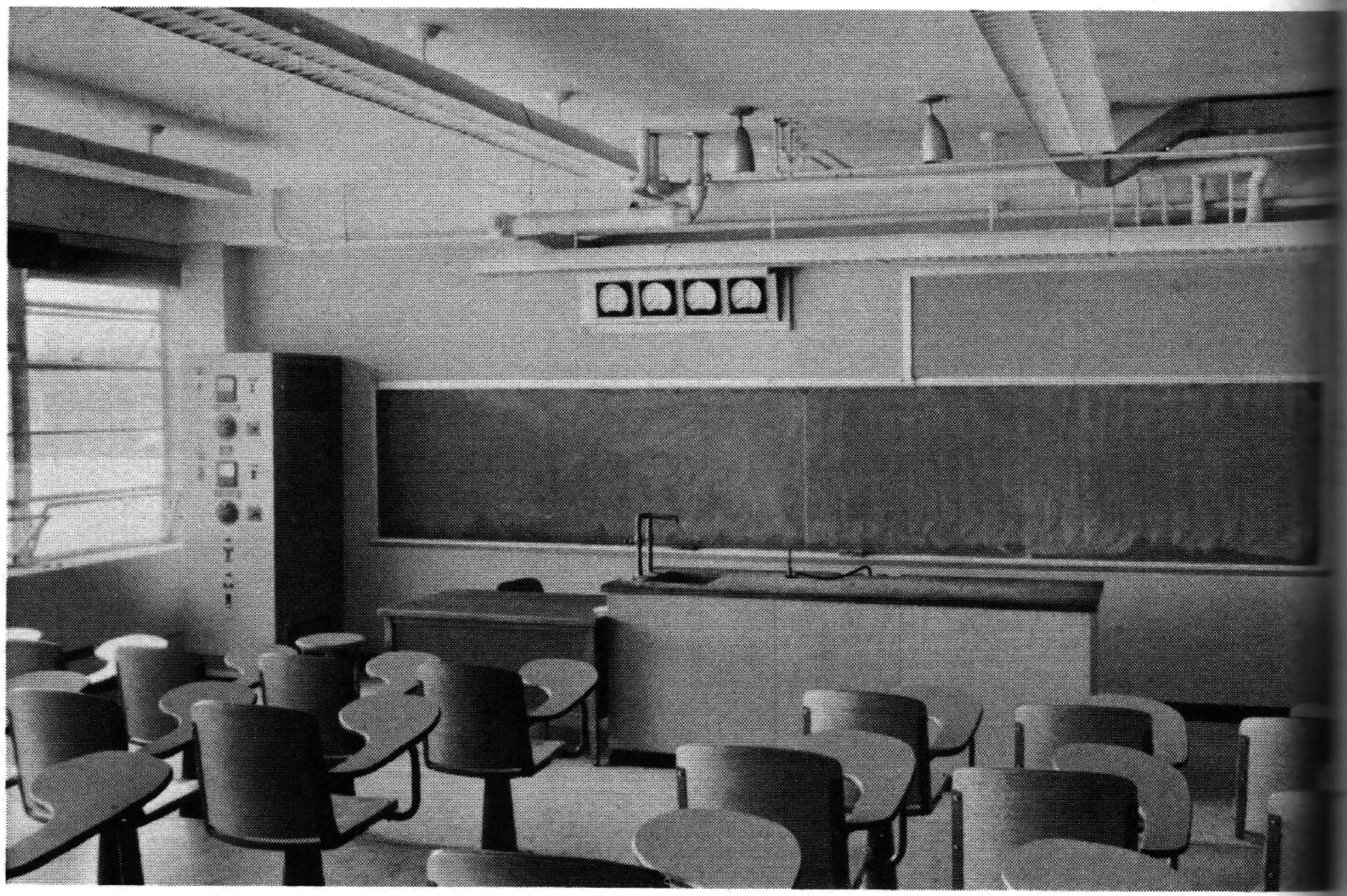

MATHEMATICS
Tackboard
MATHEMATICS
MATHEMATICS
MATHEMATICS
MATHEMATICS
M
OFFICES
W
DARK RM
Lockers
STORAGE
Down
Lockers
Sink
PREPARATION & STORAGE
PREPARATION & STORAGE
STOR
ANIMALS
STOR
PREPARATION & STORAGE
Down
Chalkboard
Stor Cab
Demonstration table
Sink
CHEMISTRY & PHYSICS
CHEMISTRY & PHYSICS
CHEMISTRY & PHYSICS
CHEMISTRY & PHYSICS
BIOLOGY
BIOLOGY
BIOLOGY
FLOOR PLAN
0
10
FEET
50
NORTH
GREENHOUSE

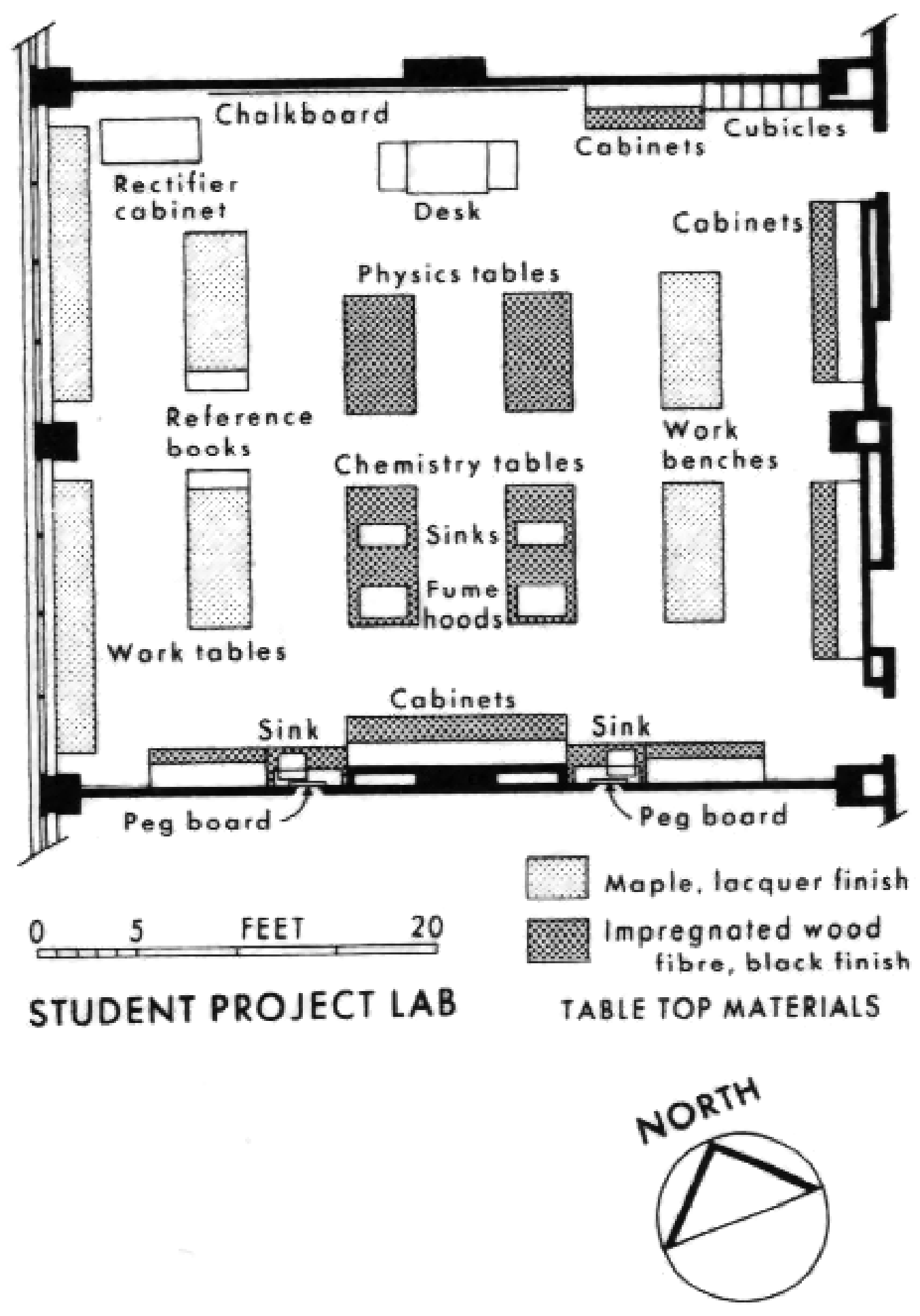
Figure 18. Floor plan of the Science-Mathematics Wing, Darien High School, Darien, Connecticut. Ketchum and Sharp, Architects, New York.

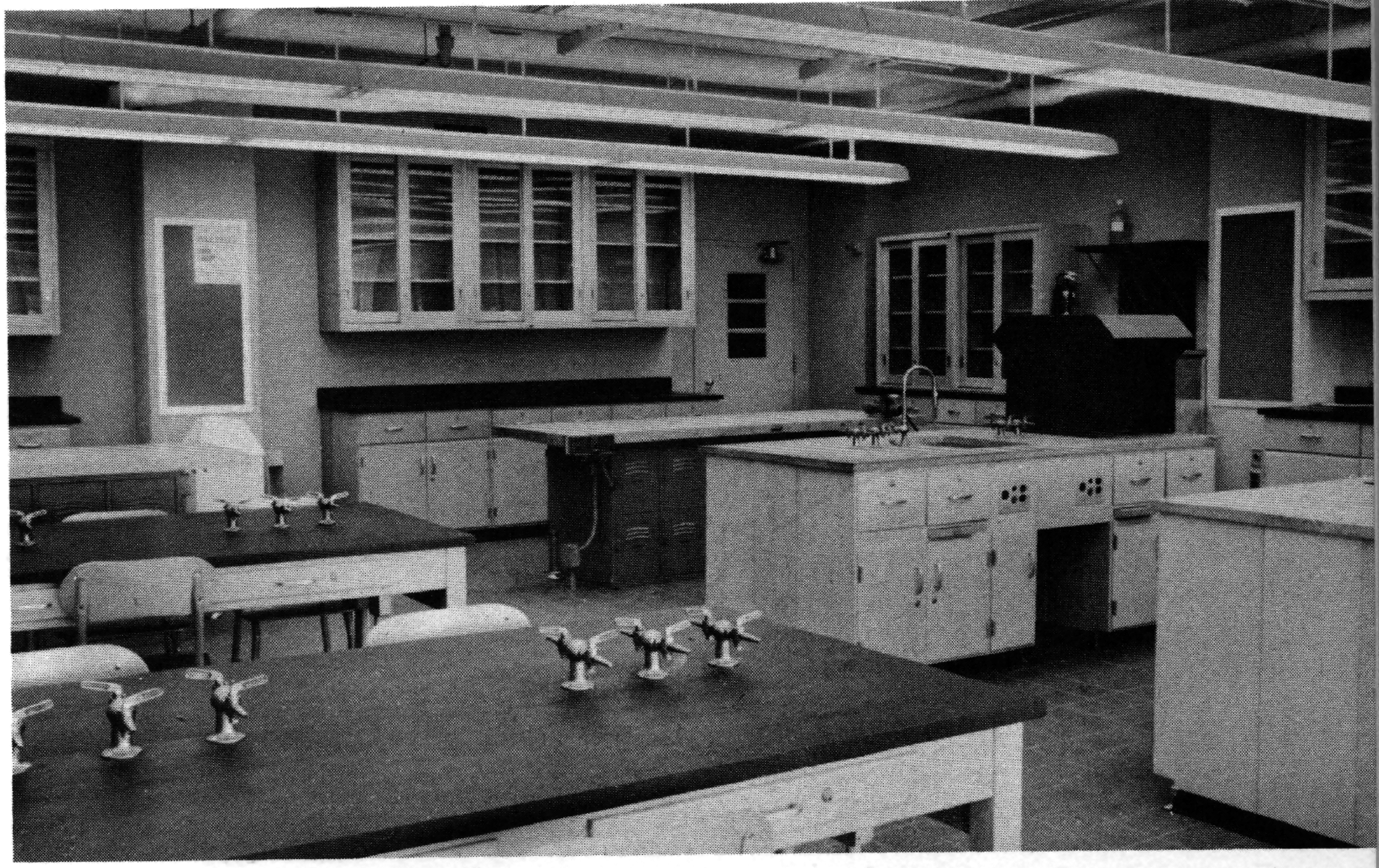
Separate classrooms and laboratories

Figure 19. Typical science demonstration room, Bronx High School of Science, New York. Note stepped floors in floor plan of Science Wing at left. Emory Roth and Son, Richard Roth, Architect, New York.

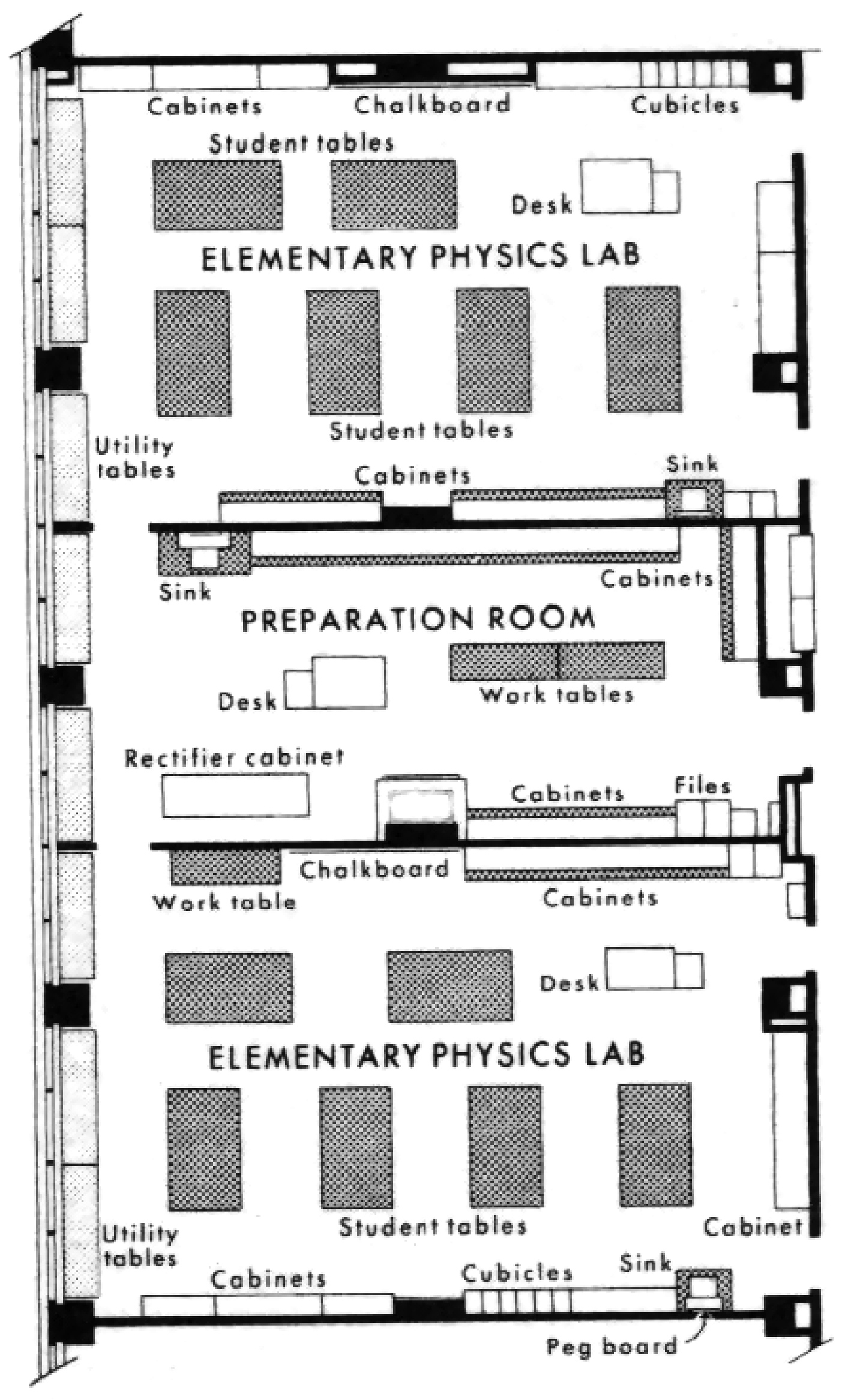

SCIENCE LECTURE HALL
MONITOR ROOM
STOR
STOR
M
W
ELEMENTARY PHYSICS LABORATORY
Jan
Boys
Up
Dn
PREPARATION ROOM
Up
Dn
ELEMENTARY PHYSICS LABORATORY
SCIENCE DEMONSTRATION ROOM
ADVANCED PHYSICS LABORATORY
SCIENCE DEMONSTRATION ROOM
PREPARATION ROOM
SCIENCE DEMONSTRATION ROOM
Elev
ADVANCED PHYSICS LABORATORY
Dn
Up
Dn
Dn
Up
SCIENCE DEMONSTRATION ROOM
Stepped floor
Ramp
Dn
0
10
FEET
50
NORTH



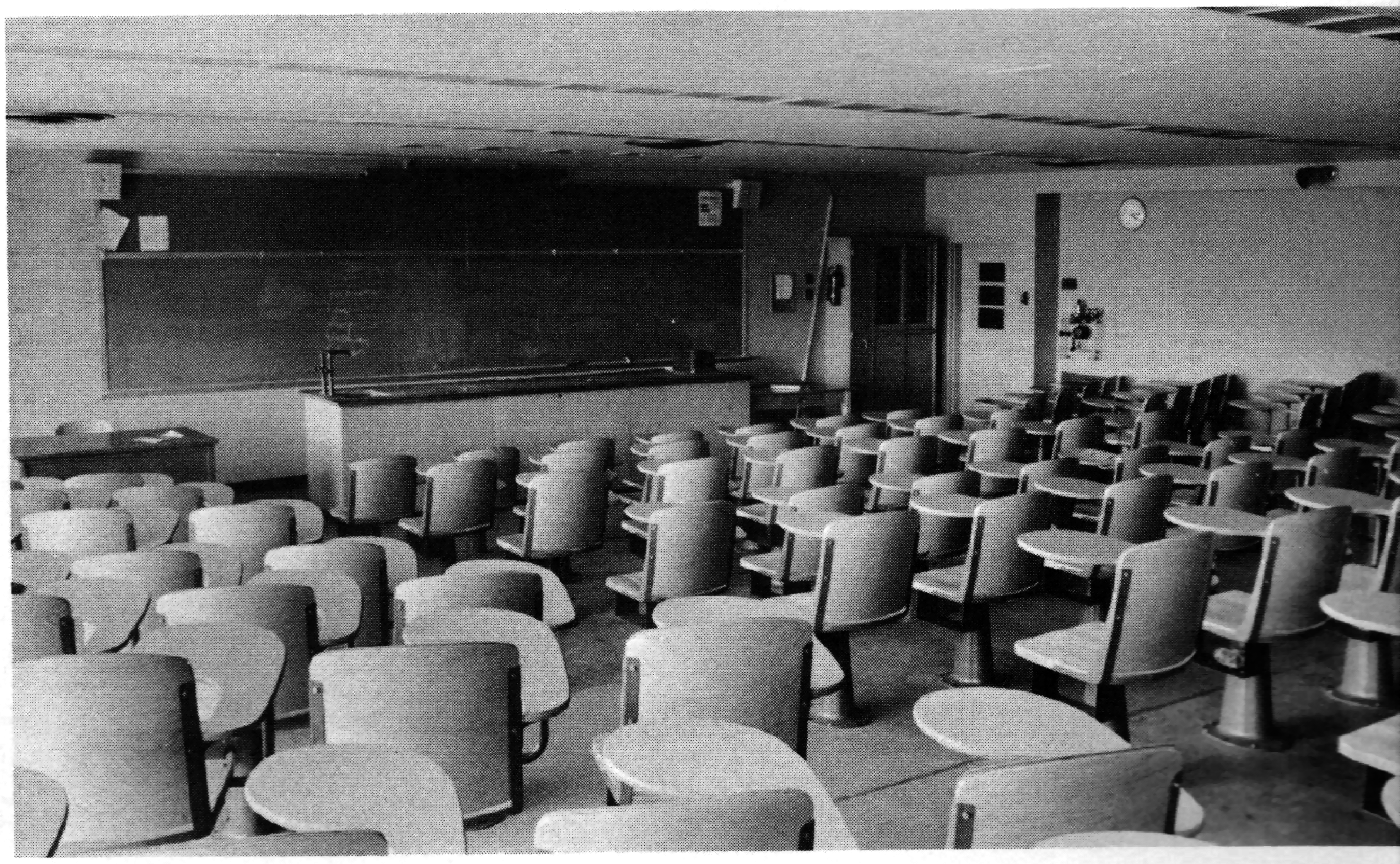

Chalkboard
Cabinets
Cubicles
Rectifier cabinet
Desk
Cabinets
Physics tables
Reference books
Chemistry tables
Work benches
Sinks
Fume hoods
Work tables
Cabinets
Sink
Sink
Peg board
Peg board
0 5 FEET 20
Maple, lacquer finish
Impregnated wood fibre, black finish
STUDENT PROJECT LAB
TABLE TOP MATERIALS
NORTH



Student project laboratory. Note down-draft fume hoods at right.

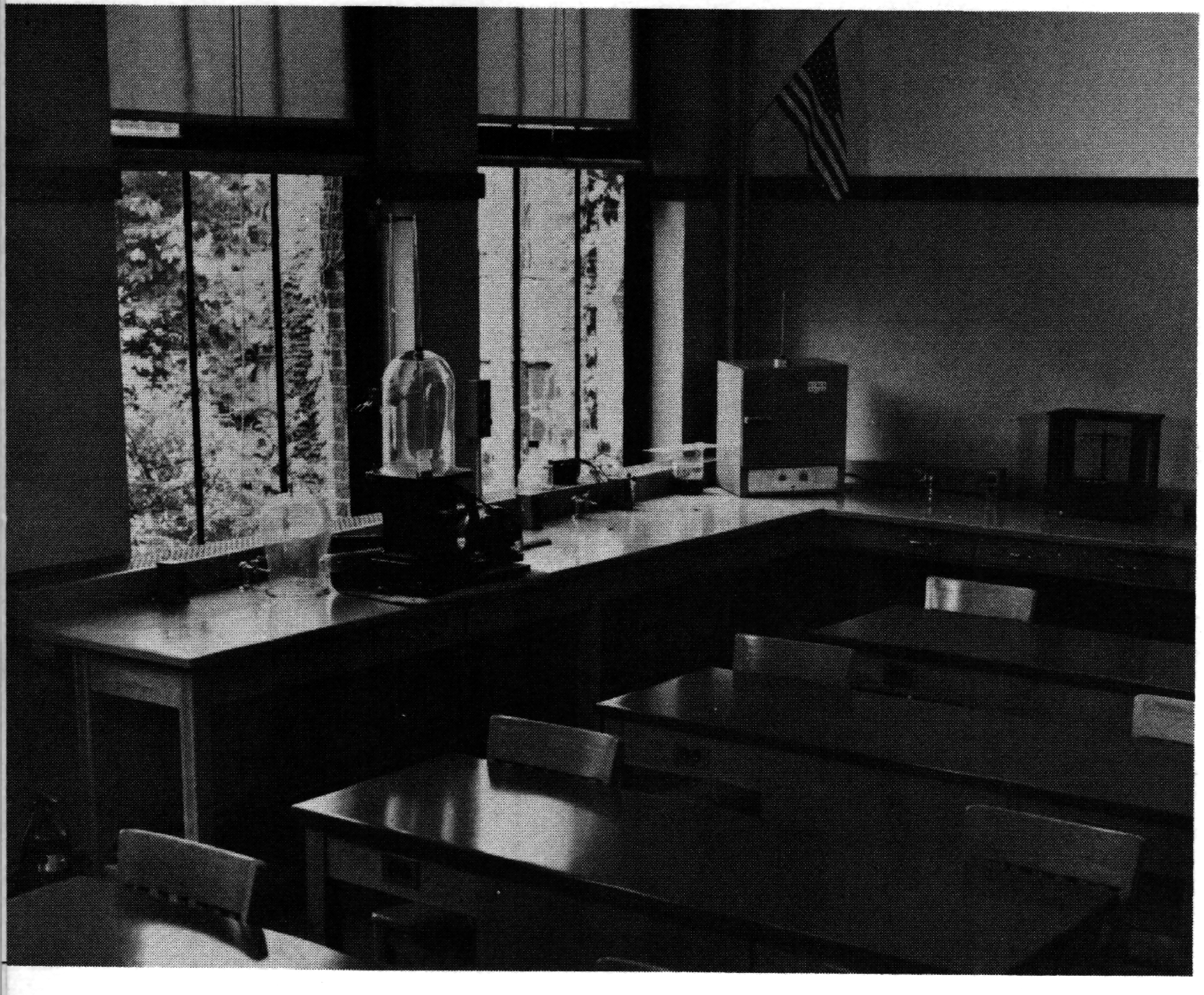

Cabinets
Chalkboard
Cubicles
Student tables
Desk
ELEMENTARY PHYSICS LAB
Utility tables
Student tables
Cabinets
Sink
Sink
Cabinets
PREPARATION ROOM
Desk
Work tables
Rectifier cabinet
Cabinets
Files
Chalkboard
Work table
Cabinets
Desk
ELEMENTARY PHYSICS LAB
Utility tables
Student tables
Cabinet
Cabinets
Cubicles
Sink
Peg board

Floor plan, elementary physics laboratories and preparation room.



Science lecture hall which seats 105 students.

The science project room



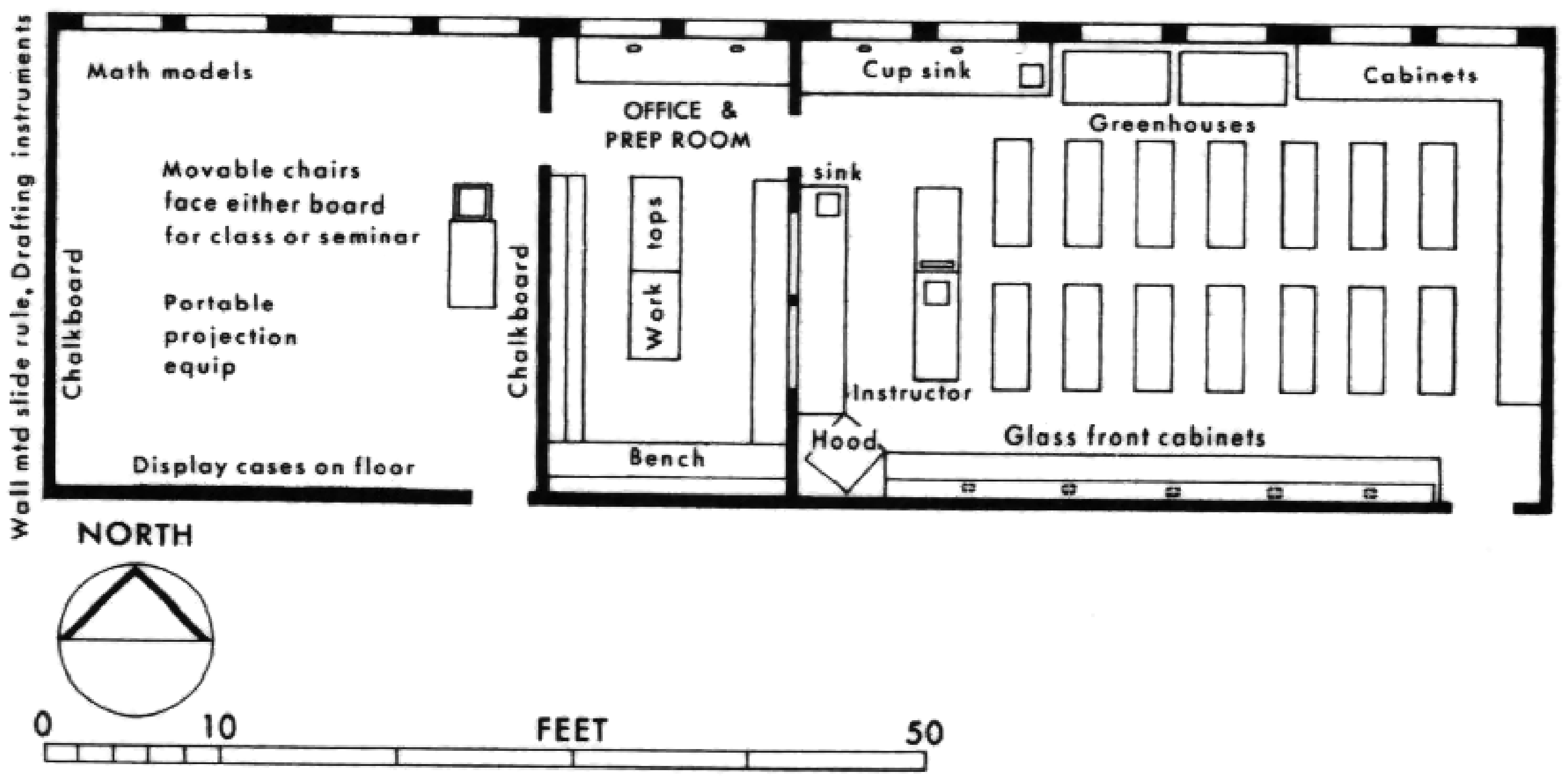

Wall mtd slide rule, Drafting instruments
Math models
Movable chairs
face either board
for class or seminar
Portable
projection
equip
Chalkboard
Display cases on floor
OFFICE &
PREP ROOM
Chalkboard
Work tops
Bench
Cup sink
sink
Hood
Instructor
Greenhouses
Cabinets
Glass front cabinets
NORTH
0
10
FEET
50

Figure 20. Science project room at Evanston High School, Evanston, Illinois. Note L-shaped bench in rear of laboratory for electrical and electronics work. Research bench in office and preparation room is shown below. Shades in slots permit darkening of room.

A CHECK LIST AND PAGE REFERENCES FOR HIGH SCHOOL PHYSICS FACILITIES

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